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EFFECTS OF VARYING THE WAVE LENGTH OF THE STIMULATING LIGHT UPON THE ELECTRICAL RESPONSE OF THE RETINA

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INTRODUCTION

When the retina of an eye is stimulated by light the nerve responses set up thereby are accompanied by changes in the electrical potential difference between portions of the nerve tissue as, for instance, between the front of the retina and the optic nerve. These changes in the electrical state of the nerves may, with considerable justification, be used as a measure of the actual nerve responses. In a previous paper[1]* by Chaffee, Bovie and Hampson, the method and apparatus adopted for the measurement of these electrical changes are described and a study of these responses is presented when the stimulating light is white. The reader is referred to this previous paper for a more detailed description of the apparatus and method than the following brief outline gives.

The eye of an etherized frog is cut in half. The posterior half containing the retina is mounted in a moist chamber shown in Fig. 1 and connections made to it through threads moistened with Ringer's solution. One thread is connected with the protruding optic nerve and the other thread is usually arranged to touch end on to a point on the front surface of the retina. These threads at their other ends connect through non-polarizable electrodes to a two-stage resistance-coupled amplifier utilizing thermionic vacuum tubes. (See Fig. 2 for a schematic diagram of the apparatus.) The output of the amplifier passes to a string galvanometer so arranged that the excursions of the string are photographed on a moving piece of bromide paper. By means

* Citation numbers throughout refer to Bibliography at end of this paper.

of this apparatus the variations with time of the potentials of the retina are magnified and automatically recorded. The stimulation is caused by light from a source the intensity of which can be adjusted to known values.

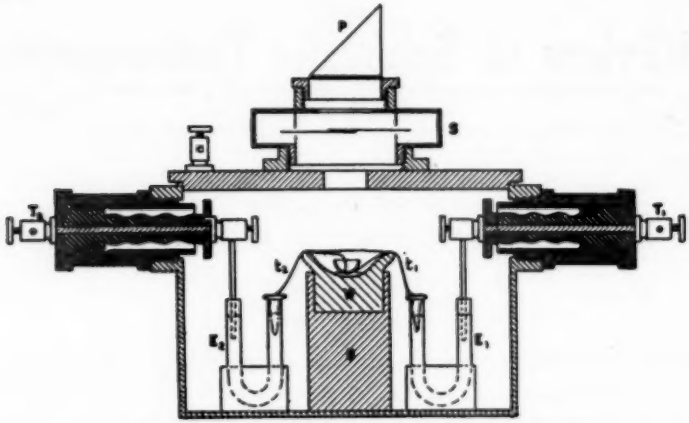

FIG. 1. *The general arrangement of the apparatus.*

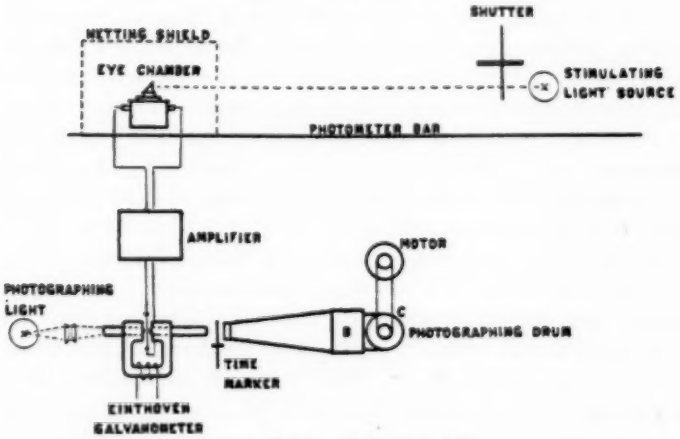

FIG. 2. *The eye chamber.*

The conclusions of the first paper are given below to furnish foundation for the present report.

1. An improved apparatus is used in studying the electrical response of the retina. This apparatus makes use of a two-stage thermionic amplifier which makes possible the measurement of small potentials with the absorption of no energy.

2. In preliminary work the electrical response was obtained when using the whole eyeball and the resulting curves are similar in principal characteristics to those obtained by previous experimenters.

3. The response curve of the whole eyeball undergoes marked progressive changes as the eye ages. The most notable change with age is the decrease in first positive increase in potential of injury and the development of a second relatively long negative deflection.

4. Much superior results are obtained by using only the posterior half of the eyeball and making direct connection to a small point on the surface of the retina.

5. Using the improved method of connection to the retina, the responses are greater, and the response curves reveal much fine structure showing that the reactions are more complex than can be explained by the two-or three-substances theories.

6. The complex curves are analysed into four definite and typical components called the first, second, third and fourth maxima. The first and second parts appear to be independent of each other. The time from the beginning of response to the first maximum is practically constant and equal to 0.27 seconds. The time to the second maximum measured in the same manner is also essentially constant and equal to 0.70 seconds. The times to the third and fourth maxima vary greatly according to the energy of light stimulation. The time to the third decreases and the time to the fourth increases as the energy increases. It is believed that the first and third maxima are related.

7. The apparently unrelated first and second maxima can be reasonably attributed to the reactions of the two types of visual cells in the retina, the cones and rods.

8. Synthetic curves resembling many of the observed curves are built up from two assumed types of fundamental curves. The two distinct types of fundamental curves are considered to be the responses of the two types of sensory receptors, the cones and rods. The shapes of the fundamental curves have been chosen with due regard to the performance of nerves.

9. The changes with time in the response curves of the posterior half of the eyeball are studied and graphs obtained The shape of the response as well as its magnitude undergoes a change with age. Responses have been obtained for twenty-two hours after excision of the eye.

10. The changes in maximum height of the response curves, used as a measure of the intensity of sensation, are plotted against the corresponding intensities of excitation. For low intensities the law

$$Sensation \propto \sqrt{Stimulation}$$

approximately holds: for medium intensities of excitation the Weber-Fechner law ($S \propto K \log I + C$) is obeyed.

While studying the responses of the eye to white light a rough experiment was made to see if any marked effects were observable with colored light. Three color screens were made, a red, a green and a blue, and adjusted in density so that the brightness of the transmitted light for all three appeared to be equal as judged by the authors and several others. The responses of the frog's eye to the three colors were by no means equal. The red gave practically no response while the blue caused a very great change in potential. Green gave a response intermediate between the blue and red. This crude test showed that the color sensitivity of the frog's eye is very different from that of the human eye. Because of this anomaly quantitative experiments using colored lights have been made and the results of these experiments comprise the main subject of the present publication.

I. HISTORICAL REVIEW

Previous investigators of the electrical response of the eye have also been interested in the effects of color upon these responses. Very little quantitative work, however, has been done, for most of the tests using colored lights have been incidental in the use of white light by the investigators and the results are in most cases merely qualitative observations.

Practically all of the earlier workers agree that the electrical response of the eye is greater for the middle of the visible spectrum than for the ends. There is some disagreement, however, concerning the wave length which gives the maximum stimulation. A few observed that the wave length which produces the maximum response depends upon intensity. It was expected that the responses for different colors would show qualitative differences which would assist in explaining color vision but there is disagreement in this particular among the investigators. More specifically the results of early work are as follows:

Holmgren[2] observed that with the frog's eye green is more potent than red or blue.

Dewar and M'Kendrick[3] stated that for a frog yellow gives greater response than green.

Chatin[4] using crustacea, insects, and mollusks believed that red and blue give the least response.

Ishihara[5] showed that the response of the frog's eye is less with red than with green.

Einthoven and Jolly[6] demonstrated that for the same energy of stimulation green light gives more response than red or blue.

Himstedt and Nagel[7] stated that for weak stimulation of a dark-adapted frog's eye a wave length of 544 mμ and for strong illumination of a light adapted eye a wave length of 590 mμ give the greatest responses.

Piper's results[8,9] indicate that for the cephalopod a wave length of 500 mμ gives maximum response. His results with a frog's eye confirm those of Himstedt and Nagel. He also stated that the rod eye of night birds and the dark-adapted human eye give maximum response for the same wave length and the cone eye of the day birds and the light-adapted human eye give maximum response for the same wave length.

Gotch[10] differed from the general trend of results and believed that the frog is more sensitive to red than to blue. He found that the latent period varies with wave length. According to him all responses are of the same general type whether evoked by colored or white light.

Waller's[11,12,13] conclusions for the frog's eye may be summed up as follows: All colors seem to act in the same direction more or less powerfully according as they are more or less luminous. There is no complementary or antagonistic influence. The eye excessively stimulated by one color shows the same fatigue for the complementary color as for all colors. In the light of the above he believes there is no qualitative effect of color.

De Haas[14] obtained results similar to Waller's and suggested that the frog may be totally color blind.

Brossa and Kohlrausch[16] made more careful experiments with color than many of the others. Subjecting the frog's eye to time exposures they stated that there is a qualitative difference in the response curves for different colors. The differences occur in the latent periods and in the shape of the curve during the latter part of exposures of several seconds. They found further[16] that this qualitative difference is absent with owls' eyes but present with pigeons' eyes.

Fröhlich[17] found oscillations in the response of the eye of the cephalopod. He concluded that the frequency and intensity of these oscillations depend upon the brightness and color of the stimulating light. He also found that the blue end of the spectrum is more effective than the red end in producing potentials in the retina.

Sheard and McPeek[18] showed that for long exposures there is a gradual shift in potential which depends upon the color of the stimulating light.

II. APPARATUS

The method of measuring and recording the electrical response of the retina has already been alluded to in the first part of this paper and described in detail in the previous publication.[1] In this previous work only white light was used. In order to make a thorough and systematic study of the effects of colored lights it was necessary to set up and accurately calibrate apparatus for giving approximately monochromatic radiation of known energy and to provide means for varying the energy as well as the color through a large range.

Fig. 3 gives a diagram of the apparatus for obtaining light of various colors. The light from a 600-watt motion-picture lamp, the current through which is maintained constant at 20 amperes, is focused by condensing lenses on the first slit S_1. A water cell is placed in the path of the light to absorb the invisible heat. Beyond slit S_1 the light is

resolved into colors by the two prisms *PP*. These prisms can be rotated by a graduated screw so that as the latter is turned the spectrum formed by the prisms travels over the second slit S_2. If this slit is narrow a limited region of the spectrum is selected, according to the position of the screw, and passes to the eye chamber. The screw for varying the color was calibrated in terms of wave length of the light.

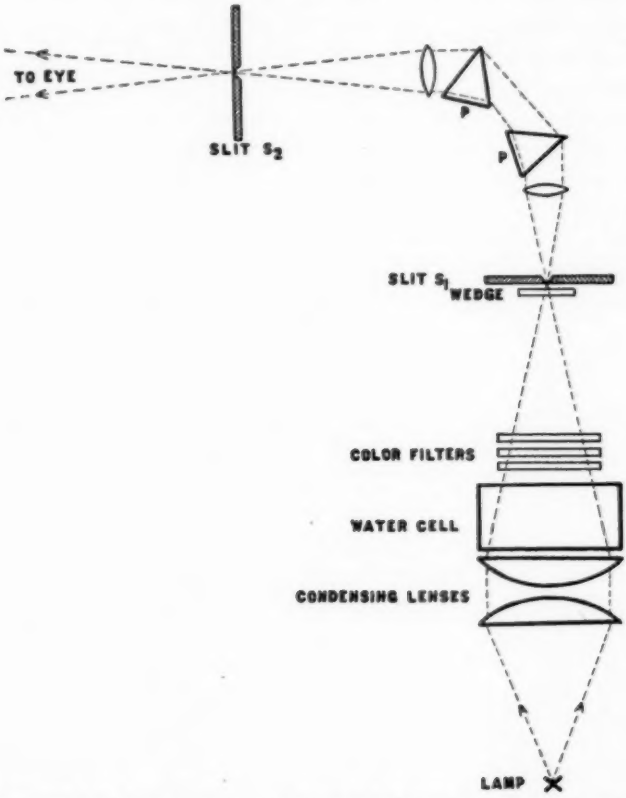

FIG. 3. *Optical system by means of which the wave length and the intensity of the stimulating light can be varied.*

Since this monochromatic illuminator gave a small amount of scattered white light together with the colored light it was necessary to use color filters for absorbing all portions of the spectrum except a narrow region about the color being used. Eight Corning-glass filters

and one dye filter, when used in certain predetermined combinations, divided the spectrum into six overlapping regions.

The tungsten lamp gives a small amount of energy in the violet end of the spectrum compared to the energy of the red radiation. Consequently, in order to reduce the energy in the red end, neutral absorbing filters were used. These filters, of which there are four of different densities, were used with the colored filters and were chosen so that the energy which passes through the whole filter combination is roughly the same throughout the spectrum.

All neutral and colored filters, with the exception of the one dye filter, are optically plane and the coloring or absorbing matter is in the glass so that these filters could be assumed to be reasonably permanent. The one dye filter which was necessary to make the series complete was always the most remote filter of the series from the lamp so as to reduce the fading to a minimum.

The intensity of any color was varied by two methods in combination. Varying the width of slit S_2 changes the intensity proportional to the slit width. The width of the slit was determined by a calibrated micrometer screw. The other method of varying the intensity was by means of a photographic wedge placed immediately in front of the slit S_1. This wedge, a photograph of which was shown in the previous paper, consists of a piece of photographic plate cut in circular form and exposed to an increasing extent around in a circle forming a circular wedge. This plate is mounted in a graduated ring so that it can be rotated. The light passes through a narrow aperture and through a greater or less dense portion of the wedge according to its setting. The wedge gives a variation of energy of approximately one hundred fold.

The relative magnitudes of light energy were measured and the wedge, slit, and color screens were calibrated by means of a Coblentz[21] vacuum thermopile connected to a sensitive Weston galvanometer.

Seventeen colors ranging in even steps from .395μ to .700μ were chosen and the setting of slit S_2 determined for each color so that the energy passing through the appropriate filter combination and slit S_2 is the same in each case. A table of the color filters and setting of S_2 for each color gave the necessary adjustments for obtaining responses to constant energy throughout the spectrum. The value of this constant energy could be increased or decreased by known amounts either by the wedge or by varying slit S_1.

III. RESULTS

The first type of experiment performed to investigate the effects of varying the color of the stimulating light comprised photographing the responses to short flashes of light of various colors while maintaining the energy of the stimuli constant. If the maximum heights of the responses be assumed to be proportional to sensation as was discussed in the first paper, then a curve plotted with maximum heights against wave length gives the color-response curve of the eye for constant energy. Such a graph is shown in Fig. 4. The striking feature about this curve is its height in the blue and violet regions of the spectrum. It might be objected that since the lens and vitreous humor have been removed in these experiments, violet and blue light which might be absorbed by these media now act directly to give apparently higher responses in the blue end. To eliminate any error due to the possible

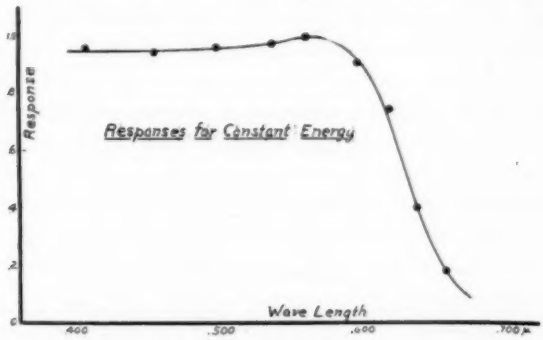

FIG. 4. *Maximum height of the response of the frog's eye for various wave lengths at constant energy.*

absorption in the lens and humor, the same type of curve was run with the whole eyeball and the resulting curve shows the same characteristics as that of Fig. 4.

In Fig. 5 a family of constant energy curves, of the same type as that of Fig. 4, is plotted, the separate curves being for different values of the energy. The relative values of the energy of stimulation are indicated on the curves. Each observation as before was taken for a flash of light of 1/25 second duration. At low intensities the responses drop in the blue end. As the intensity is decreased the wave length which gives maximum response shifts toward the violet. A shift in the sensitivity of the human eye toward the violet for low intensities has

been observed psychologically and is called the Purkinje effect. (See Parsons[20] p. 57.) The shift shown in Fig. 5 cannot be interpreted as due entirely to the Purkinje effect because the method of obtaining the results is different from the method adopted to demonstrate the psychological effect.

If, now, instead of maintaining the energy constant, the energy of the stimulating light flashes is varied by means of the wedge while the color is kept the same and the heights of the responses plotted against intensity, a curve is obtained giving the relation between response or sensation and intensity. Such a curve for green light is shown by the $I-R$ curve of Fig. 6. In order to derive the form of the mathematical

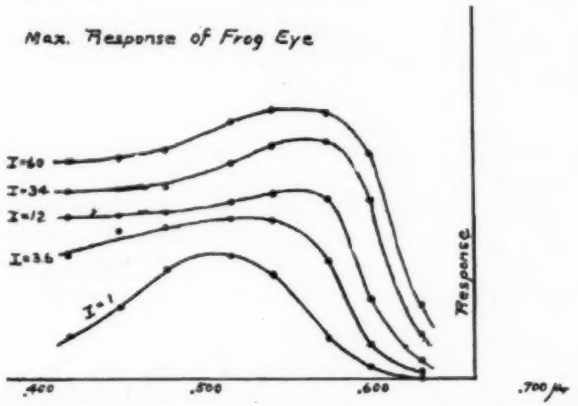

FIG. 5. *Maximum height of the response of the frog's eye for various wave lengths at constant energy for five values of the energy*

law connecting the variables, the logarithm of the response is plotted against the logarithm of the intensity yielding the $\log I - \log R$ graph of Fig. 6. This plot shows a definite straight portion. On the other hand, if R is plotted directly against $\log I$ the dotted curve of Fig. 6 is obtained which also has a straight portion. These graphs are exactly similar in all respects to the corresponding graphs for white light given in the previous paper. It is evident that the intensity-response curve can be divided into three regions, i.e., the *first* region for low intensities for which region the $\log R - \log I$ graph is straight, the *second* region of medium intensities for which the $R - \log I$ graph is straight, and the *third* region of relatively high intensities for which no law has been deduced. The responses for this third region have nearly reached a

maximum saturation value and a further increase of intensity produces only changes in the last parts of the response curves long after the cessation of the stimulus and called in the first paper the "fourth maximum."

Fig. 7 is a plot of experimental data giving the $\log R - \log I$ and the $R - \log I$ plots for three colors, the plot for green being the same as that of Fig. 6. Fig. 8 is a similar plot for five colors.

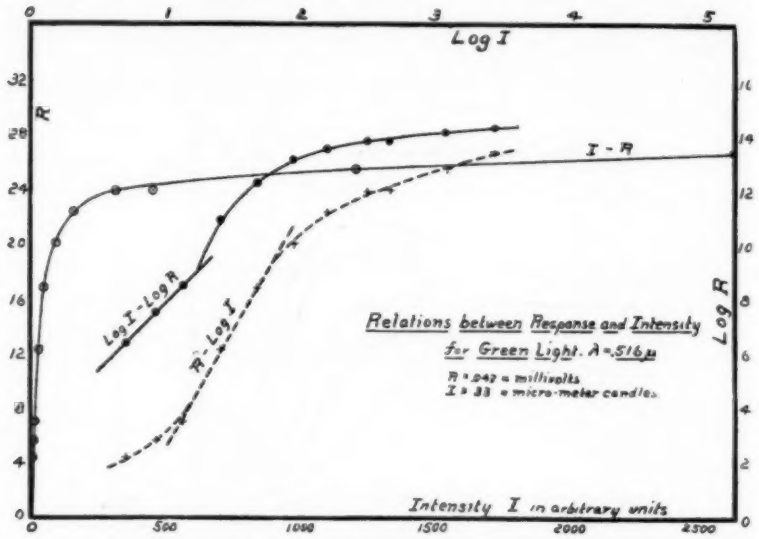

FIG. 6. *Curves showing the relation of the maximum height of the response of the frog's eye, R, to the intensity of illumination, I, for wave length .516μ.*

The possible experimental errors in obtaining data for curves of the type shown in Figs. 7 and 8 are great due largely to inherent irregularities of the apparatus and changes in the eye because of the long time required to obtain a complete set of data. Since the data for Fig. 7 were taken for only three colors, the run was correspondingly short and the error due to changing of the eye was reduced. For this reason Fig. 7 shows better the outstanding characteristics of plots of this type. Many plots of the type shown in Fig. 7 have been made and all more or less definitely conform to certain characteristics which will now be discussed referring to Fig. 7 as representative.

The notable points about Fig. 7 are that the $\log R - \log I$ plots for all colors are parallel straight lines for the first range of intensities, and

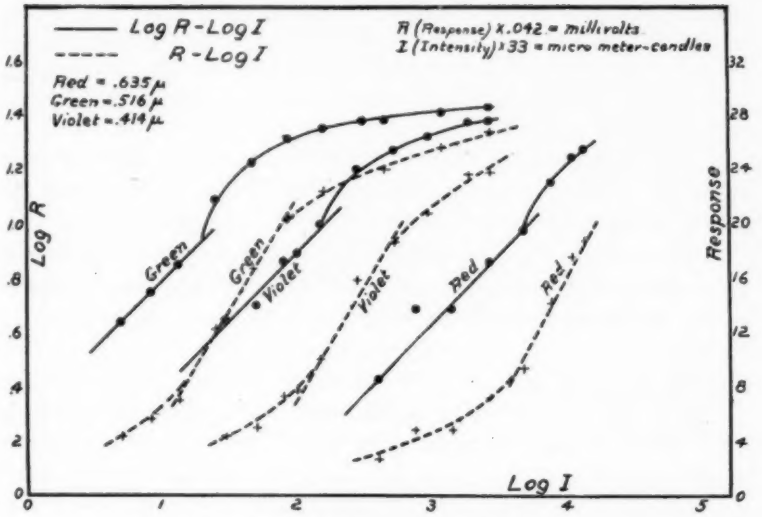

FIG. 7. *Log R-log I and R-log I plots for three wave lengths.*
R = Maximum height of response
I = Intensity (or energy) of illumination.

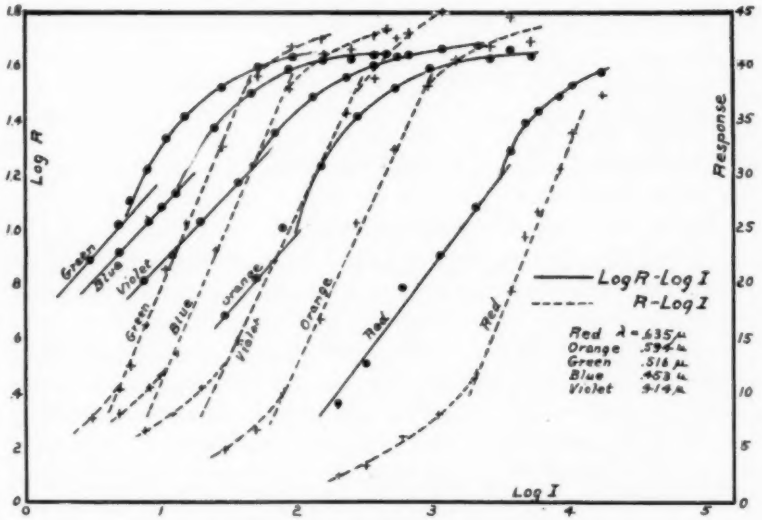

FIG. 8. *Same as Fig. 7 for five wave lengths.*

that the law breaks down abruptly at approximately the *same height of response for all colors*. The straight line $R-\log I$ graphs for the second range of intensities are *also parallel* and this law, too, breaks down at the second break point which occurs at practically the *same height of response for all colors*.

It was shown in the previous paper that for white light the responses in the first and second regions can be expressed by certain mathematical laws as follows: In the first region the law is of the form,

$$R \propto I^{\frac{1}{n}} \tag{1}$$

where the average value of n was found to be 2. The second region follows the Weber-Fechner law which can be expressed in the form

$$R = K \log I + C \tag{2}$$

where K and C are constants.

Since the plots of Fig. 7 are exactly similar in shape to the plots for white light, then the laws for the plots of Fig. 7 must be similar to those for white light.

The law for the straight line portion of the $\log R-\log I$ curve can evidently be written

$$n \log R = \log I + \log A_\lambda \tag{3}$$

or

$$R = (A_\lambda I)^{\frac{1}{n}}$$

where A_λ is a constant for any one color but a function of the wave length, and n has the value 2 for all colors.

The straight line portion of the $R-\log I$ curves can be expressed in a form similar to equation (2), i.e.

$$\frac{1}{K} R = \log I + \log B_\lambda$$

or

$$R = K \log (B_\lambda I) \tag{4}$$

where K is a constant and the same for all colors because the lines are parallel, and B_λ is a constant for any one color but a function of the wave length.

If it may be assumed, as is strongly suggested by the experimental results, that the corresponding break points in the laws all occur at the same level, or in other words, at the same response for the several colors, then it of necessity follows that the horizontal distance between the straight portions of the full-line graphs for any two colors is the same as the distance between the straight-line portions of the dotted graphs for the same colors. This is not absolutely true in Fig. 7 but the results

of a large number of similar experiments support the assumption. It is, therefore, evident that the intercepts of the two sets of straight line graphs on the log I axis, which intercepts determine the values of $\log A_\lambda$ and $\log B_\lambda$, respectively, have the same relative spacings, but those for one set, such as for the $R-\log I$ graphs, are displaced by a constant amount from those of the other set which displacement may be denoted by $\log p$. Then it follows that

$$\log B_\lambda = \log A_\lambda + \log p \qquad (5)$$
$$= \log (p A_\lambda)$$

Then equation (4) can be written

$$R = K \log (A_\lambda I) + \log p \qquad (6)$$

In equations (3) and (6) the only factor which depends upon color is A_λ, a factor which is constant for any one color but which is a function of the wave length and measures the true sensitivity of the retina to various colors independent of intensity within the range of the first and second laws.

The fact that A_λ occurs only as a multiplier of I indicates that the corresponding laws of response to the different colors are identical, but the reacting substance in the retina has a different sensitivity to the different colors.

From the above results it may be concluded that *for the frog's eye there is no qualitative difference in the laws of variation of maximum response for different colors.*

As was pointed out in the first paper the typical response to a flash of light consists of several well defined maxima the first two of which are important in this discussion. Fig. 9 presents some tracings of response curves all for the same color but different energies indicated on the curves. At low intensities, that is, intensities in the first region, the second maximum is more prominent as shown in Fig. 9 for the curves marked $I = 7.5$ and 37.5. As the intensity is increased the first maximum increases more rapidly than the second and becomes of the same height as the second maximum at the intensity corresponding to the break point between the first and second laws. At high intensities the second maximum may be so large as practically to mask the second maximum. Fig. 10 is a tracing of response curves for which the energy was the same but the colors different. Comparing Figs. 9 and 10 it is obvious that the responses go through the *same* changes in shape when the color is varied as they do when the intensity is varied. In other words, there is no qualitative *difference in shape* of the response curves

due to different colors other than what would be expected from the varying sensitivity of the eye to the several colors.

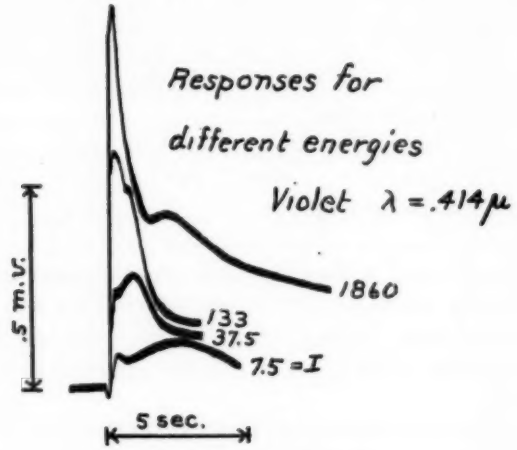

FIG. 9. *Traced response curves.*

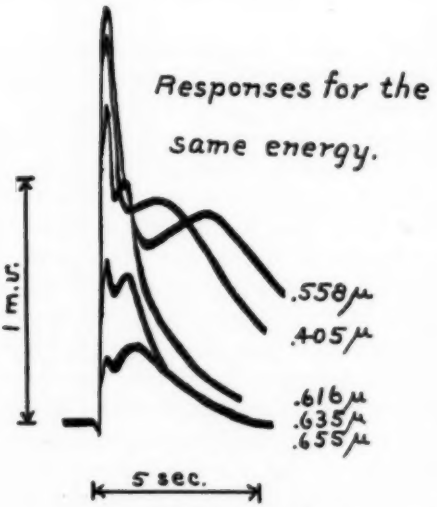

FIG. 10. *Traced response curves*

In order further to check this point the intensity for each color which would give the same height of response was derived from Fig. 8, and

experiments made in which the intensity was adjusted to these values for the several colors. Figs. 11 and 12 are tracings of the results. It will be seen that in neither figure are the heights of the responses the same as was intended but this is not surprising when it is realized that the data for setting the apparatus were obtained from the results of a

FIG. 11. *Traced response curves of the same shape for several colors.*

different eye. The curves are sufficiently close, however, to show conclusively that for the same height of response the *shape of the response curve is the same for all colors. This further confirms the conclusion that there is no qualitative difference in the main characteristics of the response curves for different colors.*

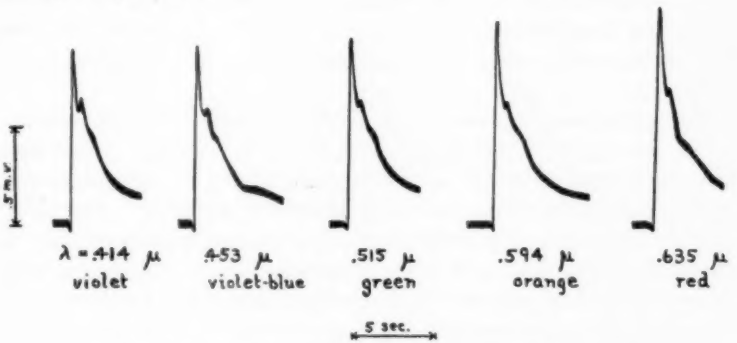

FIG. 12. *Traced response curves of the same shape for several colors.*

Brossa and Kohlrausch, in a very careful series of experiments, apparently found a qualitative difference in the shape of the responses for different colors when the intensity of time exposures was adjusted to give the same maximum response. This is contrary to the conclusions of this paper and it may be suggested that if high intensities falling in the various portions of the third region are used, the response curves

do not increase materially in height but do broaden out and without an investigation of the kind described in this paper it would be impossible to draw their conclusions.

Several experiments were made in which the eye was exposed constantly to one color and the responses measured for flashes of another color. These experiments were designed to determine if totally different mechanisms are active for different colors. The results confirm the observations of Waller in that apparently so far as the response curves show there is no selective fatigue due to exposure to a single color and that the fatigue due to one color affects the responses of all colors.

In the previous paper it was suggested that the first maximum of the response is due to the cones and the second to the rods. This conclusion is in agreement with a psychological test which is very easy to perform. If the observer's eye is illuminated by a flash of colored light so led into the eye that the eye cannot focus on any form, two sensations of light are observed the first of which is colored and the second uncolored. This is easily observed if the intensity of the colored stimulus is not too great and is more easily seen with blue and green than with red light. It has been shown in the previous paper that when the illumination is not extremely low the time to the first maximum is about .27 second and to the second about .70 second. As far as could be judged the times to the colored and gray sensations in the psychological test corresponded to these figures. Parsons[20] (pp. 87, 88) speaks of this effect.

The conclusions so far drawn from the data may be briefly summed up in the following statement. There is no apparent qualitative difference in the character of the response curves to different colors which can be used as a basis for explaining color sensation. Any differences for different colors which may be in the responses to convey to the brain the sensation of color must exist in the finer individual responses of the end organs and nerves the sum total of which make up the gross curves discussed in this paper. Response curves for different colors have been shown to conform to definite mathematical laws similar in all respects to the laws deduced for white light. The only effect of varying color is to change the value of a single parameter A_λ of the curves.

Returning now to a further discussion of the data it is interesting to deduce the color sensitivity or visibility curve of the frog's eye as has been done for human vision.

The common definition of visibility of radiant energy given for instance, in the paper by Gibson and Tyndall[19] on the "Visibility of Radiant Energy" is

$$V_\lambda = \frac{L_\lambda}{E_\lambda} \tag{7}$$

where V_λ is the visibility at wave length λ, usually expressed as relative visibility with reference to unity at the maximum; L_λ is the luminosity, and E_λ (the same as I_λ in this paper) the energy at wave length λ. This definition does not specify whether V_λ is to be determined by maintaining E_λ constant and measuring L_λ, or by keeping L_λ the same and measuring E_λ. In fact the definition implies that the two processes are equivalent which, however, is not the case.

Referring to Fig. 7, it is evident that if the color is varied while the intensity is maintained constant, the variation in sensitivity of the eye is so great that the law of response is different for different colors. If the law of response changes then of course the responses are not a function only of sensitivity. For instance, referring again to Fig. 7, suppose that the intensity were such that $\log I = 2.4$, then for red light the eye would be responding according to the $\log R - \log I$ law, for violet light the second law, $R - \log I$ would hold, and for green light the response is so great that it falls in the third region where neither law holds. It is clear that, at least for the frog, no intensity can be found for which the law of response for all colors is the same. Hence for every curve of Fig. 5 the law of response changes one or more times along the curve. According to Fig. 7 if the response is maintained constant and the energy measured which, for each color evokes this *same* response, then no matter what value of constant response is chosen the law is the same for all colors. Since the law remains constant the sensitivity is a function only of the energy and is inversely proportional to the energy. S. Hecht,[22] in a paper on the reactions of Mya to light of different colors, recognized that the only correct method of measuring the sensitivity of the organism to different colors is to determine the energy at each color which produces the same response.

It is reasonable to assume that the human eye has somewhat the same characteristics depicted in Fig. 7 so that it can be asserted that visibility should be determined by measuring the energy to produce a constant response or sensation and *not* by the converse process used for obtaining the curves of Fig. 5. Using the former process, a plot of the reciprocals of the energies referred to the maximum value of the reciprocal gives a true color sensitivity or relative visibility curve of the eye.

It is suggested that the definition for relative visibility be changed to

$$V_\lambda = \left(\frac{E_{min}}{E_\lambda}\right)_{constant\ response} \tag{7}$$

where E_{min} is the energy for that wave length requiring the minimum energy to evoke the chosen response, and E_λ is the energy at any wave length λ to produce the same response.

Practically all of the methods adopted for determining the visibility curve for man such as the "step-by-step" or "equality of brightness" method, the "flicker photometer" method, etc., measure the energy for constant values of brightness and hence the methods are justified according to the above consideration. In fact psychologically it would be very difficult to use the converse process. With the frog's eye or any eye subjected to test by the apparatus used in these experiments, it is easier to measure responses for constant energy than by cut-and-try process to obtain the same response.

Referring back to equations (3) and (6), assume that R is maintained constant. Then $A_\lambda I_\lambda$ must be constant as λ is changed. In other words, $A_\lambda \propto \frac{1}{I_\lambda}$ for constant response and hence the sensitivity of the eye to different colors is proportional to A_λ. Equation (7) for visibility can then be written

$$V_\lambda = \frac{A_\lambda}{A_{max}} \tag{8}$$

The value of $\log A_\lambda$ can be found from the intercepts of both the $\log R - \log I$ lines and the $R - \log I$ lines on the $\log I$ axis. The circles of Fig. 13 show values of A_λ determined from the $\log R - \log I$ lines of several experiments while the crosses give the values of the same quantity taken from the $R - \log I$ lines of the same experiments. The average values are shown by the large circles at the right. The ratio $\frac{A_\lambda}{A_{max}}$, or visibility from these average values is shown by circles in Fig. 14.

Although it is difficult to adjust intensities to produce the same response because the image of the galvanometer fibre moves so rapidly that the maximum deflection is uncertain, and the repeated exposures necessary to adjust the responses to the same values would rapidly fatigue the eye, nevertheless, one experiment of this sort was made. In this experiment the energy was varied for each color until the first two maxima of the response curve described above were of the same

height. It has been shown that when this is true the response corresponds to the break point between the first and second laws and hence means that the response has the same height for all colors. The relative visibilities from these data are shown by the crosses in Fig. 14. The curve averaging the crosses and circles is the best representation according to the data at hand of the true visibility curve of the frog's retina.

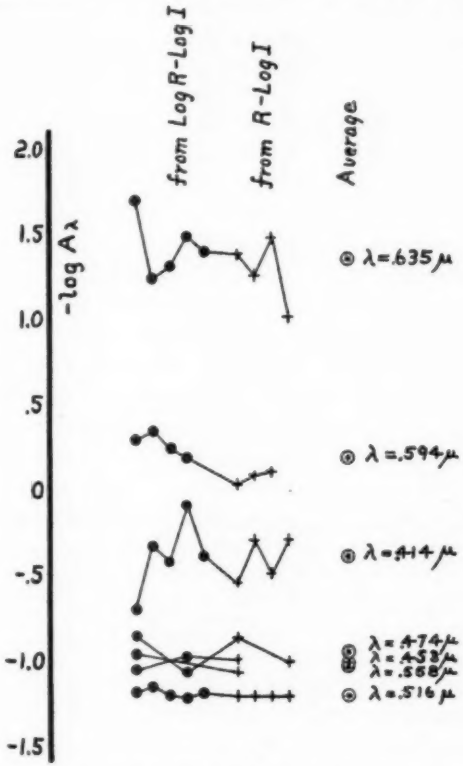

FIG. 13. *Values of (−log A) for seven wave lengths.*

The dotted curve of Fig. 14 is an average of a great many determinations of the photopic or chromatic visibility curve of human vision. This curve is taken from a paper by Gibson and Tyndall.[19]

The curves of Fig. 14 show that the visibility curve of the frog's retina is of the same general shape as, although somewhat wider than, the human photopic visibility curve, but it is displaced roughly .040μ

toward the violet end of the spectrum. The wave length which gives maximum response in the frog's retina is .516μ.

Several experiments to determine the scotopic or low intensity visibility curve for human vision have been made, probably the most successful of which is that of Hecht.[23] His curve has its maximum at .511μ and is similar in shape to the photopic visibility curve shown by the dotted curve of Fig. 14. The scotopic curve falls inside the frog's visibility curve and is reproduced in the dot-and-dash line in Fig. 14.

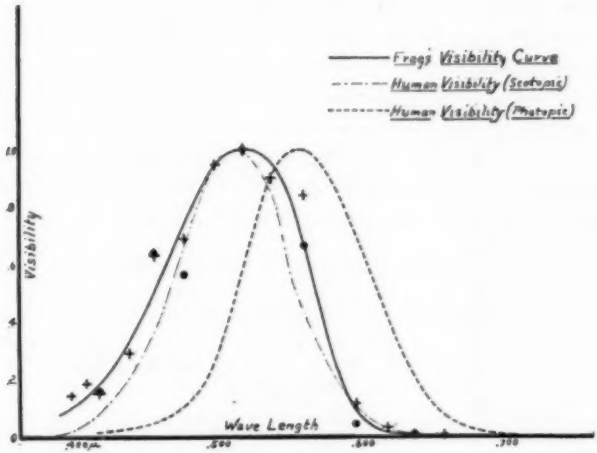

FIG. 14. *The visibility curve of the frog's eye (full line), the "adopted visibility curve"[19] (photopic) of the human eye (dotted line) and the scotopic visibility curve of the human eye (dot-and-dash line).*

Considering the three curves of Fig. 14, particularly in view of the near coincidence of the frog's visibility curve with the scotopic human visibility curve, it seems that we may entertain two hypotheses, one, that the frog has some color vision and that the full line curve of Fig. 14 represents its color sensitivity curve, perhaps somewhat modified by the presence of rod vision, and two, that the frog has no or very little color sense and that the results of Fig. 14 give the achromatic visibility curve of the rods.

In considering the first hypothesis it is important again to call attention to the fact that two laws for the height of the responses are observed, which fact strongly suggests two mechanisms in the retina

and the natural assumption, which is strengthened by the psychological test referred to on page 16 is that one law is due to the rods and the other to the cones. Furthermore, it should be emphasized that the intensities of light used in obtaining the frog's visibility curve ranged from about the threshold of vision far up into the intensities which excite the sensation of color as judged by the author's eyes. Therefore, although the experiments were made on dark adapted eyes, the intensities were great enough to give color sense if that exists in the frog. From these considerations it is reasonable to assume that the cones contribute their effect to the response curves although, as Ecker and Wiedersheims[24] show, there are about three times as many rods as cones. If then the color sensitivity curves of the rods and cones are differently situated with respect to the wave length axis, the value of A_λ obtained from the high and low intensities of stimulation should differ. As shown in Fig. 13 this is not the case, at least within the experimental error. Therefore, if the cones are active, it must be concluded that their color sensitivity curve coincides or nearly coincides with the rod curve, and both are given by the observed curve of Fig. 14.

The second hypothesis, that the vision of the frog is essentially rod vision, and that the frog has little or no color sense is supported by the relative paucity of cones, the near coincidence of the observed visibility curve and the scotopic curve for human vision, and the fact that A_λ is the same for all intensities. If this hypothesis is correct then the existence of two laws and the two humps in the response curves must be explained in some other way than ascribing them to the rods and cones.

It is impossible to decide at present which of the hypotheses is correct, or whether or not a compromise between them is more probable. Further experiments are necessary.

IV. SUGGESTIONS FOR FUTURE WORK

The results of this investigation indicate that further work is highly desirable to derive more accurately the color sensitivity curve. It would then be possible to determine if there is a difference between the visibility curves for high and low intensities and according as the eye is light or dark adapted. The range of wave lengths should be extended further into the violet.

Since the method is applicable to any eye it would be extremely valuable to obtain the visibility curves for a great many kinds of eyes including those containing only rods or only cones. Such results should

throw a great deal of light upon the evolution of color sensation and enable one definitely to separate and to determine the shapes of the response curves of the rods and cones.

It is probable that to obtain an insight into the true nature of color sensation some method must be devised for further analysing the response curves into the finer pulses arising from a single rod or cone.

V. SUMMARY OF RESULTS

1. A color illuminator, used in conjunction with color filters to exclude stray white light, was calibrated so that the eye could be stimulated with light of any known wave length and known energy.

2. The electric potentials, called electric responses, produced in the retina by the action of light, were measured by means of a thermionic amplifier connected to an Einthoven galvanometer. The measuring apparatus is the same as used in the previous paper.

The electrical responses to colored light show the same general characteristics as those to white light.

3. Curves were plotted giving the maximum height of the electrical response of the retina for various colors, the energy of stimulation remaining constant for any one curve. One of the outstanding features of these curves is the fact that the responses in the violet are relatively great for the highest intensities.

4. The maximum height of the responses was measured for varying energy for constant colors and the results conform to certain mathematical laws similar to the laws deduced for the responses to white light.

5. The results of the mathematical analysis show that for any color the intensity-response curve may be divided into three regions corresponding to three ranges of intensities. In the first region the plot of log (*response*) against log (*intensity*) is a straight line. In the second region the plot of (*response*) against log (*intensity*) is a straight line. In the third region no law has been deduced.

6. The first region for which $\log R - \log I$ is straight corresponds to the *same* range of responses for different colors but to different ranges of intensities.

7. The second region for which the $R - \log I$ plot is straight corresponds to the same range of responses for different colors but to different ranges of intensities.

8. The responses in the first region obey the law

$$R = A_\lambda I^{\frac{1}{n}}$$

where R is the response, I the intensity, n a constant and the same for all colors, and A_λ a constant for any one color but a function of wave length.

9. The responses in the second region obey the law

$$R = K \log (A_\lambda I) + \log p$$

where R is the response, I is the intensity, K and p constants and the same for all colors, and A_λ the same constant as in 8.

10. The factor A_λ is the only factor dependent upon color and hence the laws for various colors are the same, but for a different range of intensities.

11. There is no difference in the law of *maximum response* for different colors.

12. Exposures made within the limits of the two laws for different energies so adjusted as to give the maximum response the same for several colors, give responses of the same shape, so that it is concluded that there is no qualitative difference in the *shape* of responses for different colors.

13. There is no selective fatigue when the retina is exposed to light of one color.

14. As a result of 11, 12, and 13, there is no qualitative difference in the responses to different colors which can be used as a basis to explain color vision.

15. The value of A_λ for seven wave lengths is deduced from the first and second regions of several experiments and is plotted against wave length giving the true color sensitivity or visibility curve of the frog's eye.

16. The visibility curve of 15 is confirmed by observations of energy necessary to produce the same response for fourteen wave lengths.

17. A new definition of visibility is suggested which ensures that visibility be always determined by measuring the energy to produce the same response at different wave lengths; namely,

$$V_\lambda = \left(\frac{E_{min}}{E_\lambda}\right)_{constant\ response}$$

18. The constant energy curve (3) is not the true visibility curve because the laws of at least two regions are concerned in every possible curve.

19. The visibility curve for the frog's eye derived from (15) and (16) is similar in shape to the generally accepted visibility curve for color vision of the human eye but it is shifted approximately .040μ

toward the violet end of the spectrum. The maximum sensitivity occurs approximately at .516μ. This curve nearly coincides with the low intensity or achromatic visibility curve of human vision.

This paper is the second of a series of investigations on the electrical response of the retina, conducted in the J. Collins Warren Laboratory of Bio-Physics of the Cancer Commission of Harvard University. The investigation was undertaken in collaboration with Dr. W. T. Bovie. The first paper[1] of the series has already been referred to in the text. Due acknowledgment is here made of the assistance of Dr. Bovie and the Cancer Commission in this investigation.

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Laws of the Glow-Discharge.—This article consists of an assemblage of data, some of them new, on the relations between current j_n, normal cathode-fall V_n, thickness d_n of the Crookes dark space, and pressure p, in glow discharges formed in various gases with electrodes of various metals; and of a comparison of these data with a theory of the familiar "space charge" type, in which the Crookes dark space is conceived as a region through which positive ions fall freely from the negative glow to the cathode and the space charge due to the electrons proceeding in the opposite direction may be ignored. By experiments on He, Ne, A, N, and O, following previous experiments on H, it was confirmed that when the pressure of the gas is varied j_n is roughly proportional to p^2; the range of pressures examined extends from 0.75 to 5 mm Hg. It was also confirmed that d_n varies as $1/p$, and that V_n is independent of p. If we conceive the Faraday dark space as a region in which positive ions are moving inward toward the cathode, starting from its outer edge with zero initial speed and reaching the cathode with the full kinetic energy imparted to them by the cathode fall, we should have j_n, V_n, and d_n connected by the familiar space-charge relation

$$j_n = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{\epsilon}{M}}\frac{v_n^{3/2}}{d_n^2}$$

wherein ϵ represents the charge and M the mass of the ions. This equation is compatible with the observed variation of j_n as p^2 and of d_n as $1/p$ for an individual gas. Günther-Schulze took values of V_n from the literature, and values of j_n from his own experiments, for glow-discharges in the six gases He, Ne, A, N, H and O and with the two electrode-materials Al and Fe; calculated d_n from the equation and compared it with the data of his direct measurements on d_n; the maximum divergence between calculated and observed values is 40%, which—considering that the formula contains no adjustable constants and that d_n is hard to measure accurately—may be regarded as a good agreement. The assumptions that the Crookes dark space

contains only positive ions and that they fall across it unimpeded are doubtless incorrect, and the distribution of field strength through the region is known not to be in accord with the theory; so that the agreement must be regarded as due more or less to a balancing-out of the various factors which make the assumptions invalid. By varying the electrode material V_n may be varied; a change of this sort leaves ϵ and M unaffected but alters d_n, so that we cannot write $j_n = \text{const.} \times V_n^{3/2}$. Experiments with eight metals and graphite as electrode-materials, in hydrogen, showed that $V_n\sqrt{j_n/p}$ remains constant within 6% although V_n ranges from 258 to 384; this would imply, if the theory can be applied, that d_n varies as $V_n^{7/4}$, for which there is some independent evidence. A tabulation of data on V_n for thirteen metals, the values for which range from 122 volts (K) to about 230 volts (Pb, Cu, Ag, Pt, Au) indicates that there is an accurate parallelism between the values of V_n for these metals and the values of the electro-chemical potential, referred to the normal hydrogen electrode. On changing over from one gas to another, the values of V_n for all the metals move up or down by the same amount. The product pd_n, constant for any particular gas, varies more or less proportionately with λV_i in passing from one gas to another; λ representing the electron mean free path in the gas and V_i its ionizing potential. Data on the anomalous cathode fall yield the relations $V^4 = \text{const.} \times j$, and $j = \text{const.} \times p^2$. Günther-Schulze gives advice about the performance of further experiments to check the theory; notably that they should be made with electrodes approximating as nearly as possible to the state of infinite planes, so that the space charge equation will be valid in its simplest form. Some of the applications of data made even in this article are rendered uncertain by the small radius of curvature of the cathodes used.—[A. Günther-Schulze, (Reichsanstalt) ZS. f. Phys. *20*, pp. 1-20; 1923]. K. K. DARROW

Masses of the Particles emitting the Bands ascribed to Nitrogen.—Duffieux deduces the masses of the particles emitting various bands ascribed to nitrogen, by observing the interference rings produced by plates of various thicknesses and determining the greatest thickness for which the rings just remain preceptible. Presumably the principle is that by which Michelson determined the widths of narrow lines and the masses of the emitting particles. The fringes were examined with a spectroscope, and thus the visibility of the fringes produced by individual bands was individually estimated; it is not stated that the bands were resolved into lines, so that each result would seem to relate to the maximum width of the lines comprised in the band. The conclusion is that the bands of the first positive group, those of the negative group, and the so-called cyanogen bands, are attributed to nitrogen atoms; those of the second positive group, the fringes of which are much more distinct than those of the first group when observed under identical conditions, are ascribed to the molecule. —[M. Duffieux; C. R. *178*, pp. 474-476; 1924.] K. K. DARROW

A CORRESPONDENCE PRINCIPLE FOR ABSORPTION

By J. H. Van Vleck

Einstein has shown that an ensemble of Bohr atoms whose orbits are distributed among the various stationary states in accordance with statistical mechanics will be in equilibrium under Planck black body radiation provided

I. The probability that an atom in the stationary state r emit light of frequency ν_{rs} and pass to the stationary state s is given by $A_r^s+B_r^s\,\rho(\nu_{rs})$, with ν_{rs} of course determined by the Bohr frequency condition, $h\nu_{rs}=W_r-W_s$. $\rho(\nu)$ denotes the specific energy density.

II. The corresponding probability of a reverse transition in which light of the same frequency is absorbed is given by $B_s^r\rho(\nu_{rs})$.

III. The coefficients B_s^r, B_r^s, A_r^s, which are independent of the energy density and temperature, satisfy the relation[1]

$$B_s^r=B_r^s=A_r^s c^3/8\pi h\nu_{rs}^3. \tag{1}$$

To avoid complexities in notation we shall assume that there are only three orbital frequencies, $(\omega_1,\ \omega_2,\ \omega_3)$, and hence only three quantum numbers $(n_1,\ n_2,\ n_3)$, but the generalization of all the equations in the present discussion to include more frequencies and quantum numbers occasions no difficulty. With this simplification the orbits can be expanded in multiple Fourier series of the form

$$q=\Sigma_{\tau_1\tau_2\tau_3}A^{(q)}_{\tau_1\tau_2\tau_3}\cos\left[2\pi(\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3)\,t+\epsilon^{(q)}_{\tau_1\tau_2\tau_3}\right]$$

where $q=x$, y, or z and where the summation is to be taken over all positive and negative integral values of τ_1, τ_2, τ_3. The spectroscopic frequency ν approaches asymptotically at long wave lengths the particular combination overtone $\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3$ of the orbital frequencies for which τ_1, τ_2 and τ_3 are equal to the changes in the quantum numbers between the initial and final states.

The rate at which energy is radiated through *spontaneous* transitions from the state r to the state s is proportional to $A_r^s h\nu_{rs}$. If at long wave lengths this is sensibly equal to the rate at which light of frequency $\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3$ is emitted by a classical conninuously-radiating electron describing a similar orbit, it is well

[1] We shall for simplicity assume in the present discussion that the system is non-degenerate.

known that the probability coefficient A_r^s must have approximately the value

$$A_r^s = (2\pi)^4(1/3c^3)e^2\nu_{rs}^3 A_{\tau_1\tau_2\tau_3}^2 h^{-1} \tag{2}$$

where $A_{\tau_1\tau_2\tau_3}^2$ is $A_{\tau_1\tau_2\tau_3}^{(x)2}+A_{\tau_1\tau_2\tau_3}^{(y)2}+A_{\tau_1\tau_2\tau_3}^{(z)2}$ evaluated for an orbit having the same size and shape as the stationary state r. This is the basis for the correspondence principle for intensities so successfully developed and applied by Bohr, Kramers, and others.

The considerations of the preceding paragraph relate primarily to emission in the absence of a radiation field, and no attempt is ordinarily made thoroughly to reconcile the quantum theory terms $B_r^s\rho(\nu_{rs})$ and $B_r^s\rho(\nu_{rs})$ with the classical mechanism of absorption. The writer, however, has computed on the basis of the classical mechanics the rate of absorption of energy by an arbitrary multiply periodic orbit in a field of radiation. For the case of three orbital frequencies this proves to be given by

$$dW/dt = \Sigma_{\tau_1\tau_2\tau_3} K_{\tau_1\tau_2\tau_3} \tag{3}$$

where

$$K_{\tau_1\tau_2\tau_3} = (2\pi^3/3)e^2\left\{\rho(\nu)\left(\tau_1\frac{\partial D_{\tau_1\tau_2\tau_3}}{\partial J_1}+\tau_2\frac{\partial D_{\tau_1\tau_2\tau_3}}{\partial J_2}+\tau_3\frac{\partial D_{\tau_1\tau_2\tau_3}}{\partial J_3}\right)\right.$$
$$\left.+D_{\tau_1\tau_2\tau_3}\frac{\partial\rho}{\partial\nu}\left(\tau_1\frac{\partial}{\partial J_1}+\tau_2\frac{\partial}{\partial J_2}+\tau_3\frac{\partial}{\partial J_3}\right)(\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3)\right\}$$

and where $D\tau_1\tau_2\tau_3 = (\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3)A^2\tau_1\tau_2\tau_3$. Here $\rho(\nu)$ and $\partial\rho/\partial\nu$ are to be evaluated with $\nu = \tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3$. J_1, J_2, and J_3 denote the intrinsic momenta which are associated with the frequencies ω_1, ω_2, ω_3 and which according to the quantum conditions are to be set equal to n_1h, n_2h, n_3h. It is readily verified that for a linear oscillator or a rotator the general result stated in (3) reduces to the values derived by Planck and Fokker respectively for the absorption in these two special cases. In the summation any particular term $K\tau_1\tau_2\tau_3$ taken by itself represents a resonance effect between the combination overtone $\tau_1\omega_1+\tau_2\omega_2+\tau_3\omega_3$ and the impressed light of nearly this frequency, and would be the only term of importance if $\rho(\nu)$ were of vanishing intensity except in the vicinity of this frequency.

The result given in (3) proves to be quite different even at long wave lengths from the quantum theory expression $h\nu_{rs}B_s^r\rho(\nu_{rs})$ for the average rate of absorption of energy by an orbit provided B_s^r is determined by (1) and (2). As suggested in part to the writer by Dr. Breit, the solution for this difficulty is that the classical absorption

must be compared not with the true rate of absorption in the quantum theory, but with what we shall call the differential rate of absorption, where by the latter is meant $h\nu_{rs}B^r_s\rho(\nu_{rs}) - h\nu_{st}B^t_s\rho(\nu_{st})$. The states r, s, and t are to be so chosen that if the quantum numbers of the state s be denoted by n_1, n_2, n_3, then those for the state r are $n_1+\tau_1$, $n_2+\tau_2$, $n_3+\tau_3$, while those for the state t must be $n_1-\tau_1$, $n_2-\tau_2$, $n_3-\tau_3$. ν_{rs} and ν_{st} are in general unequal but approach each other asymptotically at long wave lengths. That is to say starting with a given orbit of very large quantum numbers there is in the terminology of Einstein both a positive and a negative "Einstrahlung" of nearly the same frequency, and it is the difference of the two which is to be compared to the classical absorption. This we shall term the correspondence principle for absorption. Using the values of B^r_s and B^t_s given by Eqs. (1) and (2) it can easily be verified that at long wave lengths, where differences can be replaced by differentials, the differential rate of absorption in the quantum theory reduces to the classical rate of absorption (Eq. 3) for an orbit of the same size and shape as that of the state s. We can therefore say that the correspondence principle for absorption can be derived from that for emission, and conversely. In other words, Eq. 1 demands that at long wave lengths the quotient of the differential rate of absorption to the spontaneous emission have just the classical value for the ratio of absorption to emission.

In order to investigate the causes for the asymptotic connection mentioned above, the writer has examined according to strictly classical theory the distribution of multiply periodic orbits in a field of radiation given by the Rayleigh-Jeans formula $\rho(\nu) = 8\pi kT\nu^2/c^3$. Equilibrium between emission and absorption has been shown by Planck and Fokker to result for the special cases of linear oscillators and rotators, but it now appears that equilibrium is retained under a much more general type of motion. It is found that for an arbitrary multiply periodic system the statistical distribution given by the Boltzmann probability function $w(J_1, J_2, J_3) = ge^{-W/kT}$ is preserved in a classical black body field and that the emitted energy is just equal to the absorbed energy and has the same spectral distribution, provided the energy becomes infinite with each of the J's, and provided the amplitudes and energy vanish with the J's. These assumptions are similar in general character to those ordinarily made in statistical mechanics but are not realized in actual orbits, as the vanishing of

certain quantum numbers gives collisions with the nucleus and negatively infinite energy.

Details of the computations will be published elsewhere.[2]

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MINNEAPOLIS, MINNESOTA,
APRIL 7, 1924.

Change in Conductivity of Certain Lenard Phosphors, Induced by Cathode Ray Bombardment.—Various samples of Lenard phosphors, packed between condenser plates, are bombarded by 30000-volt electrons, and the current across the phosphor is measured during and after the bombardment. Measurements are made both upon the phosphor, and upon a sample of material differing from the phosphor only in that the heavy metal atoms are omitted, leaving the calcium sulphide (or zinc sulphide) and the neutral diluent salt. The differences between the currents in the two substances are attributed exclusively to the metal atoms. This extra current due to the heavy metal atoms increases at first with the electric field, and then approaches a saturation value; increases at first proportionately to the proportion of heavy metal atoms, and then approaches a saturation value; increases at first with the duration of the bombardment, then passes through a maximum and falls off to a comparatively low value. The distribution of potential within the phosphor, which is linear before the bombardment commences, alters under the bombardment and resembles the potential distribution in a thermionic tube controlled by space charge (it is determined with a sounding needle.) The author thinks that the extra current is due to secondary electrons excited by the primary electrons, i. e. those of which the displacement from heavy metal atoms to sulphur atoms is responsible for the phosphorescence. An attempt to evaluate the number of electrons excited per metal atom is made. [E. Rupp, Heidelberg; Ann. d. Phys. *74*, pp. 127-144; 1924.] K. K. DARROW

[2] Since the writing of the present article, Dr. H. A. Kramers has published in *Nature* (May 10, 1924) a very interesting formula for dispersion, in which the polarization is imagined as coming not from actual orbits, but from "virtual oscillators" such as have been suggested by Slater and advocated by Bohr. Kramers states that his formula merges asymptotically into the classical dispersion. To verify this in the general case, the writer has computed the classical polarization formula for an arbitrary non-degenerate multiply periodic orbit. This formula is the analogue of Eq. (3) of the present paper, and is more complicated than the ordinary Eq. for dispersion by linear oscillators. By pairing together positive and negative terms in the Kramers formula, a differential dispersion may be defined resembling the differential absorption of the present article. It is found that this differential quantum theory dispersion approaches asymptotically the classical dispersion by the general multiply periodic orbit, the behavior being very similar to that in the correspondence principle for absorption. This must be regarded as an important argument for the Kramers formula.

ALGEBRAIC METHODS FOR THE CALCULATION OF COLOR MIXTURE TRANSFORMATION DIAGRAMS

By Clara Lillian Froelich

In the paper entitled "The Transformation of Color Mixture Equations from One System to Another; Graphical Aids," by Herbert E. Ives,[1] the methods of constructing the diagrams which constitute the final "graphical aids" are presented, for the sake of clearness, in graphical terms. Where, however, the highest accuracy is desired, and where facilities for performing computations rapidly are at hand, the construction of such charts is advantageously performed by algebraic means. This is particularly true of Figs. 6 and 9 of the paper referred to, the originals of which were, in fact, constructed algebraically. It is the purpose of this paper to explain the algebraic method developed by the writer, working under Dr. Ives' direction.

The object of this presentation is two-fold. In the first place, the description of the method may prove of value to any who may desire to construct similar diagrams, using other fundamental data. In the second place, the algebraic methods developed for constructing these graphical aids actually constitute new modes of handling the transformations in question which compare favorably in simplicity and accuracy with previously published purely algebraic treatments.[2] The terminology used throughout this paper is the same as that in the paper of Dr. Ives referred to above.

I. *To Transfer a Working Primary Triangle to the Unit-Sensation-Sum Plane;* To illustrate the facts which are known, we shall make use of Fig. A.[3] The triangle $Y_1G_1B_1$ is the working-primary triangle, the coordinates of whose vertices are known. Its sides are unequal in length, and carry scales determined by dividing each side into equal parts. Similarly, $Y_2G_2B_2$ is the working-primary-hue triangle obtained by projecting $Y_1B_1G_1$ on the unit-sensation-sum plane.

[1] Franklin Institute Journal, p. 23; Jan. 1923. Table and figure numbers enclosed in brackets in the present paper are to be understood as referring to Dr. Ives' paper.

[2] Franklin Institute Journal, p. 673; Dec. 1915.

[3] Fig. 4 in the paper by Ives.

The problem is to find the scale of the working-primary-hue triangle $Y_2G_2B_2$ which corresponds to equal divisions in the working-primary triangle.

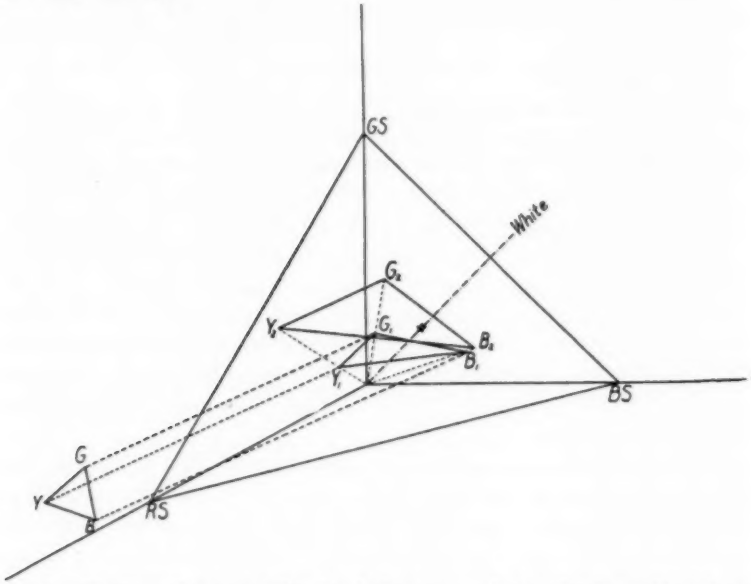

FIG. A. *Diagrammatic representation of projection processes for transforming working primary values to fundamental sensation values.*

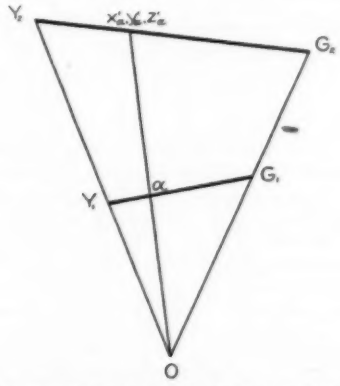

FIG. B. *Diagram used in the explanation of the algebraic method for finding the scale in the unit-sensation-sum plane corresponding to equal divisions in the working primary plane.*

Let us consider the plane-figure pictured in Fig. B which is similar to Fig. 5 of the paper by Ives. In this figure Y_2G_2 is the side of the working-primary-hue triangle; Y_1G_1 is the corresponding side of the working-primary triangle; 0 is the origin of rectangular coordinates and the whole is a face of the tetrahedron $Y_2G_2B_2O$. We wish to establish the relationship between points on Y_1G_1 and corresponding points on Y_2G_2.

Let G_1 be the end of the scale which is numbered 0, and Y_1 the end which is numbered 1. Also let a be the number corresponding to any other scale division. This scale division then divides the line Y_1G_1 into two parts whose ratio is $\frac{a}{1-a}$. Its coordinates can therefore be defined in terms of the coordinates of the end points of the line. If the coordinates of points Y_1 and G_1 are x_1, y_1, z_1, and x_2, y_2, z_2, respectively, the coordinates of the scale point x_a, y_a, z_a, are[4]

$$\begin{aligned} x_a &= a(x_1)+(1-a)x_2 \\ y_a &= a(y_1)+(1-a)y_2 \\ z_a &= a(z_1)+(1-a)z_2 \end{aligned} \qquad (1)$$

The hue line through this point and the origin meets Y_2G_2 in the point x_a', y_a', z_a'. Consequently, x_a', y_a', z_a', and x_a, y_a, z_a, bear the following relationship to each other

$$\begin{aligned} x_a' &= kx_a \\ y_a' &= ky_a \\ z_a' &= kz_a, \end{aligned} \qquad (2)$$

k being a multiplier which is as yet unknown.

Since x'_a, y'_a, z'_a, lies in the unit-sensation-sum triangle, its coordinates must also satisfy the equation

$$x_a'+y_a'+z_a'=1 . \qquad (3)$$

Hence,

$$k = \frac{1}{x_a+y_a+z_a} . \qquad (4)$$

Combining equations (1), (2) and (4) and solving for x_a', y_a', z_a', we find

$$\begin{aligned} x_a' &= \frac{a(x_1-x_2)+x_2}{(1-a)(x_2+y_2+z_2)+a(x_1+y_1+z_1)} \\ y_a' &= \frac{a(y_1-y_2)+y_2}{(1-a)(x_2+y_2+z_2)+a(x_1+y_1+z_1)} \\ z_a' &= \frac{a(z_1-z_2)+z_2}{(1-a)(x_2+y_2+z_2)+a(x_1+y_1+z_1)} . \end{aligned} \qquad (5)$$

[4] See C. Smith, Solid Geometry, p. 3.

These equations give the coordinates of points on Y_2G_2 in terms of α and the known coordinates of the vertices of the working-primary triangle. A set of α values may now be substituted in equations (5) and the coordinates of the corresponding scale division on Y_2G_2 determined.

Practically, however, it is easier to obtain the location of each point on Y_2G_2 by measuring off distances than by plotting co-

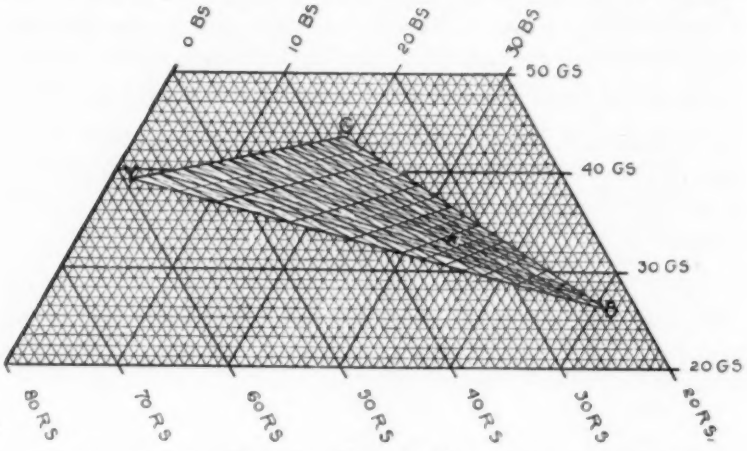

FIG. C. *The working primary triangle transferred to the equal-sensation-sum plane.*

ordinates. This may be accomplished by determining the distance of the point from G_2 by means of the formula

$$d_\alpha = \sqrt{[x_\alpha' - x_2']^2 + [y_\alpha' - y_2']^2 + [z_\alpha' - z_2']^2} \,. \qquad (6)$$

The values obtained are reduced to the scale of the drawing in Fig. C (Fig. 6) and laid off along YG starting from G. (In Fig. C, YGB is the working-primary-hue triangle with the subscripts dropped.)

Upon performing the same process for the other two sides and joining corresponding points in the three sides, the working-primary-hue triangle and its scale are obtained. It is shown in Fig. C.

Summing up the method of procedure, we have the following rules:

(1) To locate the coordinates of the vertices of the working-primary-hue triangle and of the division points of the sides, use equation (4).

(2) To find the distance between any vertex and any scale division point, use equation (6).

II. *To Inscribe Equal Purity Lines in a Color-Triangle Plot of the Spectrum:* The required diagram is of the type shown in Fig. 9 of Ives' paper, and in Fig. E of this paper where other fundamental data are used, as will be described later. By means of this figure it is possible to determine the amount of spectral color, on a luminosity scale, to be mixed with white to match all colors from white to the spectrum. White is located at 0.333, 0.333, 0.333 and the spectrum is the outer curve on which wave lengths are indicated. It is required to find the relative mixing proportions, on a luminosity scale, of all points between these two boundaries.

The spectrum is plotted with coordinates obtained by transforming the values in Table I[5] to give unit quantity of color, this transformation being necessary to place the spectrum on the unit-

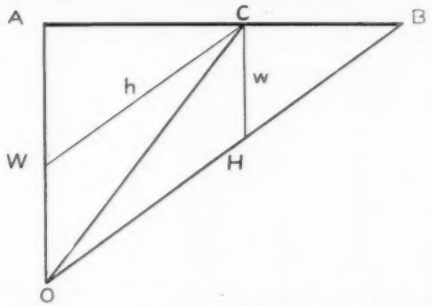

FIG. D. *Diagram used in the explanation of the algebraic method for finding the percentage ratios of the amount of spectral color to the amount of white, measured in luminous units, for every color from white to the spectrum.*

sensation-sum plane. Lines are drawn from the white center to each wave length and divided according to the method about to be described; then the corresponding points are connected and curves similar to those in Fig. E are obtained.

Consider now the triangle whose vertices are the white point, a spectrum color lying on the unit-sensation-sum plane, and the origin of coordinates.

In Fig. D, AB is the line from white through a color C, extended to the spectrum at B; W is the length of the white hue line between the origin of rectangular coordinates and the unit-sensation-sum

[5] Of the same form, but using different fundamental data, as Table II in the paper by Ives

plane and represents unit amount of white; H is the length of a color-hue line between the same limits as W and represents unit amount of spectral color. W and H yield luminosities of amount L_w and L_s, respectively. We aim to find the percentage ratios of the amount of spectral color to the amount of white for every color on AB. These amounts are to be measured in luminous units; they constitute the saturations.

TABLE 1

Wave Length in Millimicrons	Luminosity of White Light Spectrum	Interference Spectrum of Sunlight for Dieterici		
		RS	GS	BS
.400				.092
.410	.001			.195
.420	.003			.294
.430	.009			.385
.440	.019			.460
.450	.032		.017	.498
.460	.052		.039	.475
.470	.081		.069	.415
.480	.127	.018	.098	.268
.490	.194	.045	.125	.142
.500	.307	.083	.179	.092
.510	.485	.135	.260	.057
.520	.693	.200	.317	.036
.530	.850	.250	.355	.025
.540	.945	.287	.380	.017
.550	.993	.311	.387	.010
.560	.996	.320	.360	.006
.570	.956	.315	.300	.003
.580	.873	.300	.227	.002
.590	.760	.278	.158	.001
.600	.633	.250	.100	
.610	.504	.214	.057	
.620	.380	.169	.025	
.630	.263	.123	.006	
.640	.172	.082	.001	
.650	.104	.0488		
.660	.059	.0277		
.670	.031	.0145		
.680	.016	.0075		
.690	.008	.0038		
.700	.004	.0019		
.710	.002	.0009		
.720				

As the luminosity of a color is the sum of the luminosities of the elements combined to produce the color, we can resolve the luminosity of a color into its components. Thus the luminosity of C is the sum of the luminosities of the vectors, h and w, into which OC may be resolved. But the luminosity of h is $\frac{h}{H}L_s$ and the luminosity of w is $\frac{w}{W}L_w$. Hence, the proportion of spectral color measured by luminosity (saturation) is

$$p=\frac{\frac{h}{H}L_s}{\frac{h}{H}L_s+\frac{w}{W}L_w}.$$

But $$\frac{h}{H}=\frac{AC}{AB};\ \frac{w}{W}=\frac{CB}{AB}=\frac{AB-AC}{AB}.$$

Hence,

$$p=\frac{AC\cdot L_s}{AC\cdot L_s+(AB-AC)\,L_w},$$

or, using α as before for the ratio $\frac{AC}{AB}$,

$$\alpha=\frac{p}{\frac{L_s}{L_w}(1-p)+p}. \qquad (7)$$

As soon as the values of L_s and L_w are known we may substitute percentages for p and determine the location of the corresponding points.

We shall now discuss L_w, the luminosity of unit amount of white, and L_s, the luminosity of unit amount of spectral color, by the aid of Fig. 10 in the paper by Ives. It is called Fig. F in this paper. We may denote the ordinates of the green, blue and red sensation curves by g, b, and r, respectively. If the width $d\lambda$ of the shaded strip about any wave length λ is made small enough, the area of the strip becomes $r\,d\lambda$, $g\,d\lambda$, or $b\,d\lambda$, according as the strip is on the red, green, or blue curve. We know that the colors were so chosen that the total of R, G, and B yielded white; hence, the areas under the three sensation curves are equal and the total area represents the amount of white formed by the combination; consequently, if A_c is the area of one of the curves, $3A$ is the total amount of white formed.

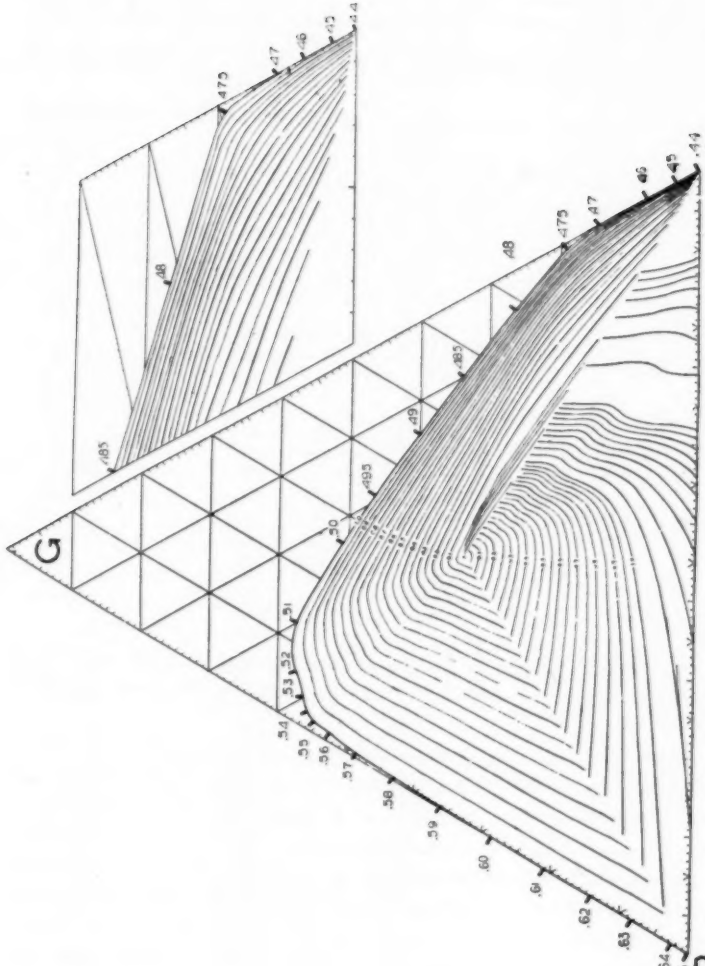

FIG. E. *The fundamental sensation triangle, showing (outer curve) the position of the spectrum (inner curves) the amounts of the spectral colors, on a luminosity scale, to be mixed with white to match all colors from white to the spectrum.*

Then, if it is desired to have the mixture represent unit amount of white, the ordinates must be divided by $3A_e$; about any wave length the sum $r\,d\lambda+g\,d\lambda+b\,d\lambda$ divided by $3A_e$ equals the amount of spectral color in that interval.

We will now proceed to determine the luminosity of spectral color of amount $\frac{(r+g+b)d\lambda}{3A_e}$. The luminosity curve was obtained for a certain amount of white which we may call a_w. This amount a_w produces a luminosity A_L found by integrating the luminosity curve. Then the luminosity of unit amount of white is $\frac{A_L}{a_w}$, that is

$$L_w=\frac{A_L}{a_w},$$

and the luminosity of any narrow band on the spectrum is $\frac{L_\lambda}{a_w}d\lambda$, where L_λ is the ordinate at the wave length of the color.

After both curves have been reduced to these units the area of the narrow band on the luminosity curve at any wave length measures the luminosity of the amount of spectral color within the corresponding band, which amount can be obtained by summing up the areas of the narrow strips on the sensation curves. That is: the luminosity of amount $\frac{r+g+b}{3A_e}\,d\lambda$ is $\frac{L_\lambda}{a_w}\,d\lambda$.

Hence, the luminosity of unit amount of spectral color is

$$L_s=\frac{L_\lambda\cdot 3A_e}{a_w(r+g+b)}.$$

It is possible now to write the expression for the desired ratio $\frac{L_s}{L_w}$. We have

$$\frac{L_s}{L_w}=\frac{3A_e}{A_L}\cdot\frac{L_\lambda}{r+b+g}.$$

This factor is substituted in equation (7) and the equation of a becomes

$$a=\frac{p}{\frac{3A_e}{A_L}\cdot\frac{L_\lambda}{(r+b+g)}(1-p)+p}. \tag{8}$$

Equation (8) may be rewritten

$$p=\frac{a\cdot\frac{3A_e}{A_L}\cdot\frac{L_\lambda}{(r+b+g)}}{(1-a)+a\cdot\frac{3A_e}{A_L}\cdot\frac{L_\lambda}{(r+b+g)}} \tag{9}$$

giving a formula for p in terms of a, the ratio of the distance, white to color, to the distance, white to spectrum, thereby providing a

means of determining a purity directly from the position of a color on the color triangle without the necessity of drawing and interpolating between the equal purity lines. It requires that the color be plotted in the color triangle before the purity may be fixed (through α) but the plotting is necessary anyhow to get the dominant wave length.

We may now sum up the process of constructing Fig. E from the data of Table I, noting that the L_λ, r, g, and b of the discussion just given correspond to the L, RS, GS, and BS, of the table:

(1) Plot the L_λ, RS, GS, and BS values to an arbitrary scale of ordinates, and the same scale of abscissae, and determine the areas of the resultant curves. These areas give the factor $\frac{3A_e}{A_L}$. (It is suggested that it would be desirable to make a practice of tabulating the color mixture data in such units as to make $\frac{3A_e}{A_L}$ equal unity.)

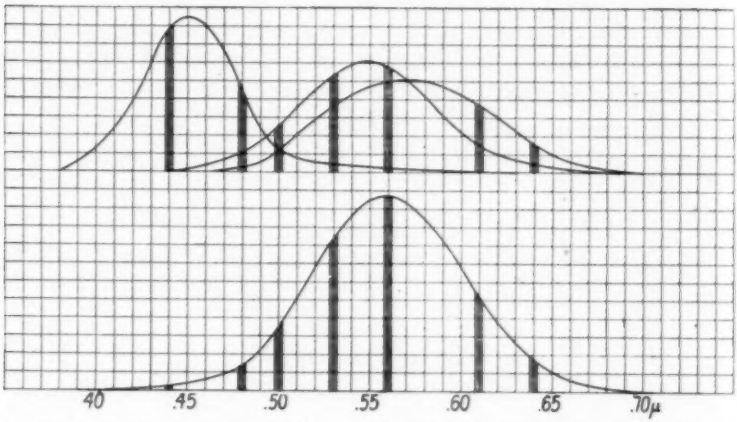

FIG. F. *Luminosity curve and sensation curves for white light (5000° black body), divided into strips for transformation process from trichromatic to monochromatic system.*

(2) Substitute the values of Table I for any wave length in equation (8), introducing any chosen saturation (p), and determine the corresponding values of α.

(3) Calling AB the length of a line in Fig. E from white to the spectral color at the wave length under consideration, compute AC, the length of the line from white to the chosen saturation from the relation $\alpha = \frac{AC}{AB}$.

(4) Repeat the process for a number of wave-lengths and connect corresponding points. The resultant curves will be the lines of equal saturation shown in Fig. E.

III. *Application to the "Elementary Sensation Curves of Dieterici:* The algebraic formula here developed for purity (9) differs from the one given by Ives,[6] namely

$$p = 1 - L_w = 1 - \frac{(a'w - av)\,(L_R + L_G + L_B)}{(u - v)\,(aL_R + a'L_G + a''L_B)},$$

in that, like the graphical method for which it was worked out, it does not depend on ascribing luminous values (L_R, L_G, L_B) to the three primaries. It *assumes the accuracy of the luminosity curve* and warps the mixture curves to fit it, while the algebraic method using the luminosity coefficients *assumes the mixture curves to be correct,* and builds up a luminosity curve from them. If the luminosity and mixture data are entirely consistent the mixture curves, upon assigning appropriate luminosity values to the primaries, should sum to the true luminosity curve, and the two methods of calculation should be exactly equivalent. No set of color mixture curves can be considered satisfactory until such a complete check is possible. Actually, as has been pointed out, the averaged Koenig data used by Ives do not sum to a good match with the best white light luminosity curve, being particularly defective in the blue region. Consequently, as a step toward arriving at more satisfactory color transformation data, other sets of mixture data have been studied. Out of the data of Koenig's observers, the sensation curves of Abney, and the elementary sensation curves of Dieterici,[7] the last have been selected as worthy of closer study for the reason that they do sum to a very close approximation to the latest luminosity curve, namely, that of Gibson and Tyndall.[8] Their approximation to this luminosity curve is shown in Fig. G where the luminosities $L_R = 0.695$, $L_G = 0.296$, $L_B = 0.008$ are used. In Table I Dieterici's values are given, together with a white light (5000 degrees B.B.) luminosity curve, to such units that $\frac{3A_c}{A_L} = 1$. In Fig. E is given the color triangle with equal purity lines computed from equation 8.

[6] Franklin Institute Journal, p. 684, Dec. 1915. In the symbols used in that paper, a, a', a'' are the color triangle coordinates (sum = unity) of the color; u, v, and w are the color triangle coordinates of the spectrum color giving the dominant hue.

[7] Koenig, Ges. Abh. zur Physiologischen Optik, p. 287.

[8] Bulletin of Bureau of Standards, p. 475; Aug. 1923.

Fig. E differs considerably in appearance from the previous plot of the averaged Koenig data, the chief difference being in the position and character of the points representing the ends of the

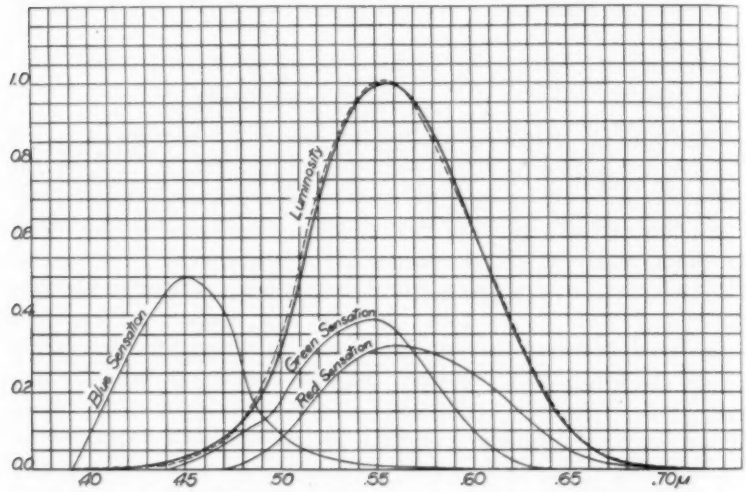

FIG. G. *Elementary sensation curves of Dieterici together with a white light (5000° B. B.) luminosity curve. The dash line is the sum of the three sensation curves plotted to luminous values.*

spectrum. Tests of the agreement of the computed hue and purity values with experimental data will be given in another connection.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH CO.
AND WESTERN ELECTRIC COMPANY, INC.
APRIL 4, 1924.

Deviations from Stokes' Law displayed by certain of Lenard's "Phosphors"—The α-band in the phosphorescence spectrum of CaSBi, extending as far down as 407 mμ in the direction of decreasing wave lengths is excited by any one of the three wave lengths 313, 405, and 436, and extends down to the stated limit in each case, although the last-mentioned wave length is decidedly greater than 407 mμ. Especial care was taken to avoid admixture of higher frequency light with the light of wave length 436. The difference between 407 mμ and 436 mμ, corresponding to about 1/5 volt, is small enough to be ascribed to transfer of energy from the thermal energy of the substance to the displaced electron. Similar results with SrSBiα and ZnSCuα. [E. Gudden, (Göttingen) Phys. ZS. *24*, pp. 465-467; 1923]. K. K. DARROW

INSTRUMENT SECTION

THE SELENIUM OPTICAL DENSIMETER*

FOR COLORIMETRIC WORK

By Elmer V. Hjort with Alexander Lowy and Oswald Blackwood

The sources of error in results of colorimetric analyses may be attributed largely to the "personal equation." In order (1) to eliminate this "personal equation," (2) to work with more widely varied dilutions, and (3) to increase the range of colorimetric method to greater concentrations, a device was constructed in which galvanometer readings are substituted for visual color comparisons. To produce this type of apparatus, substances sensitive to light may be employed to determine the relative light intensities. In the present form of apparatus, selenium is used. The relative light absorptions of different substances may be measured by the variation of the galvanometer readings in a circuit which includes the selenium cell.

To utilize a selenium cell for accurate colorimetric comparison, it should conform to the following principles: (1) A cell should be chosen which has a minimum of fatigue and a maximum of sensitivity. (2) Owing to the fatigue effect, it is desirable that the light incident on a selenium cell should be as constant as possible, therefore the beam through the test solution should be quickly replaced by one through a known solution (in a wedge). (3) The cell should be highly sensitive to all wave lengths. Such a cell has not yet been perfected.

In this new apparatus, because of the selective sensitivity of the selenium for certain colors, the comparison is not one of color (as in colorimeters), but of the quantity of the light absorbed. Because of this selective sensitivity, it may be said that the method affords a measure of the absorption of red, and to a lesser degree, of orange light. The solutions studied in this work are the salts of copper and nickel which have a pronounced absorption in the red.[1]

* This report is an abstract of a thesis presented by Elmer V. Hjort in partial fulfilment of the requirements for the degree of Doctor of Philosophy, October, 1923.

[1] Wood: "Physical Optics." Fig. 7. The MacMillan Co., 1914.

APPARATUS (See Fig. 2.)

The details of construction are given in the diagrams of Fig. 1 (Diagrams 1-8).

Front view (Diagram 1).

View of section (Diagram 2) containing: wedge, cell containing test solution, and slits.

N, Bildwell[2] type selenium cell of 13 meg-ohms resistance, in circuit with the galvanometer *U*, and the battery *V*. The cell was covered with a thin opaque sheet of paper, containg a slit one and one half millimeters wide and ten millimeters long, so that the full light from slits *O* and *P* (diagram 2) would more than cover the exposed portion of the cell.

U, Leeds and Northrup galvanometer: Resistance, 126 ohms; current constant, 0.032 microamperes per millimeter.

FIG. 1. *Front view of apparatus.*

V, Battery of dry cells furnishing approximately twenty volts.

B, Six volt, fifteen watt automobile lamp with concentrated filament. Rated at thirty one candle power.

C, Mirror, 1″x¾″, to reflect the light from the lamp *B* through the cell *G* and the slit mechanism *I* and *J* onto the selenium cell *N*. It can be adjusted both as to angle and elevation. If necessary, the beam can be made to pass through the buffer cell *K*.

C′, Same as *C* except that the light goes through the wedge *A*.

G, Cell with parallel glass sides, (diagram 6) four millimeters apart, to contain the solution to be determined. Constructed of a core of redmanol, to which glass plates have been cemented with deKhotinsky wax. (Corrosion of the cementing material makes the glass cells on the market useless.)

A, Double wedge constructed of same materials as cell *G* (diagram 3) one section (*b′*), of which contains distilled water to correct for refraction, and the other (*b*) some suitable

[2] Benson: "Selenium Cells." p. 7, 1919, Spon and Chamberlain, London.

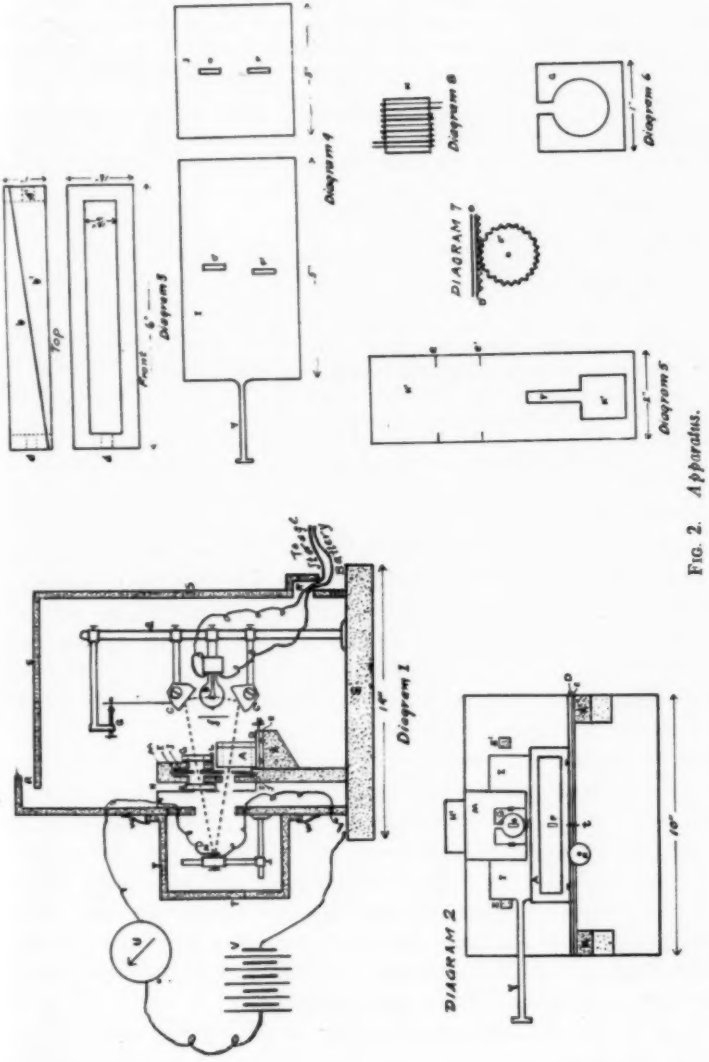

FIG. 2. *Apparatus.*

solution. It can be shown by Lambert's Law and Beer's Law that the light transmitted through a solution is a function of the thickness of the absorbing layer.

I and *J*, Slit mechanism (diagram 4) so arranged that the selenium cell receives light alternately from *C* and *C'*. The sheet of brass *I* slides back and forth before the similar sheet *J* in such a manner that when the handle *Y* is pushed to the right, the slit *P* is over the slit *P'*, and light passes through the wedge *A*. When the handle is pulled to the left, slit *O* is over *O'* and light passes through *G*.

K, Buffer cell to decrease the intensity of the beam of light. It may be placed behind *G* or *A* as desired. Diagram 5 shows the carrier for the buffer. It is a block *H'*, sliding in the slot *H* (diagram 1). The cell fits tightly into the slot *K'*. The opening (*r*) admits light through the upper slit when *K'* is behind the wedge.

M, Wooden block to place *G* over the middle of *A*.

L, Metal clip to hold *G*.

D, Carrier for the wedge *A*, sliding on a rack and pinion.

D', Rack (diagram 7).

F', Pinion (diagram 7).

F, Knob for operating rack and pinion.

Q, Device for slightly altering the position of *C*.

T, Box painted black on the inside for enclosing the selenium cell.

O and *P*, Front view of slits. (In diagrams 2 and 4).

Z and *Z'*, Stops for slit mechanism. (In diagram 2).

Y, Handle for operating slit mechanism. (In diagrams 2 and 4).

t, Pointer indicating the position of wedge on a scale not shown in diagram 1. (Diagram 2.)

f, Shield for lamp, to cut down the heating of the solution, and to keep direct rays from entering the slits.

METHOD OF OPERATION

The method of operation will be shown by means of a typical determination, (copper in copper nitrate). The light beams from the mirrors are first adjusted so that the galvanometer deflections are equal when the cell G and the wedge A are not in the path of the light. This is done by changing the position and angle of the mirrors by means of the appropriate set screws.

For calibrating the wedge, solutions of different concentrations of copper nitrate are prepared by the dilution of a previously analyzed stock solution. A solution of copper nitrate containing one half on one percent copper is placed in one unit of the wedge, the wedge is placed in position, the lamp is turned on and the selenium cell circuit closed. The light is allowed to pass through the thin portion of the wedge for at least five minutes. This is to allow the selenium cell to come to equilibrium under the influence of the same sort of light that is to be used in the determination.

The 0.51 percent solution of copper is placed in the cell *G* and the cell placed in position. The slit *O* is opened by means of the handle *Y*, allowing light to pass from the mirror *C*, through the solution in the cell and onto the selenium cell *N*. After sufficient

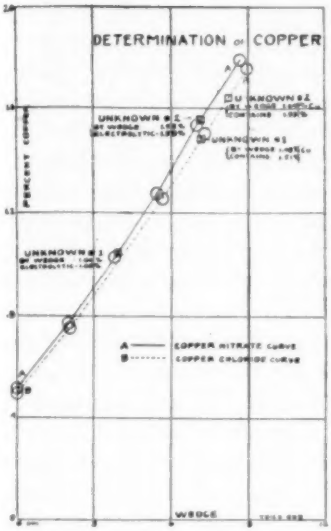

FIG 3

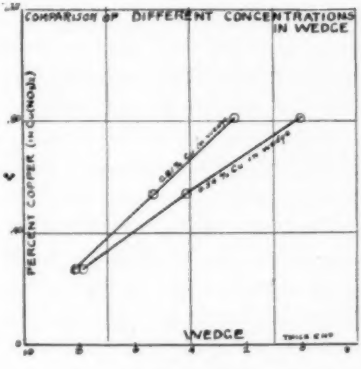

FIG. 4

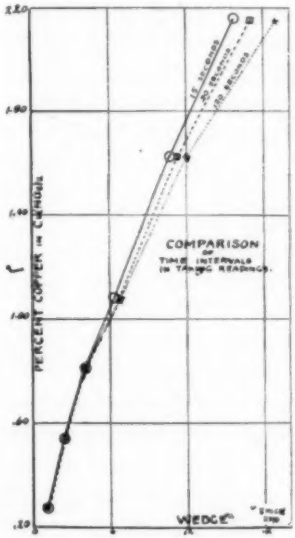

FIG 5

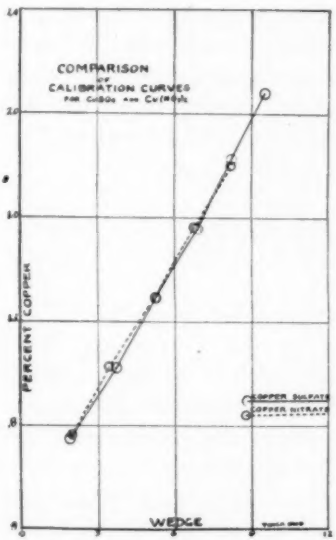

FIG. 6

time for the selenium cell to come to equilibrium under the new illumination (about fifteen seconds with this concentration of solution; the time required will increase with increasing concentration) the galvanometer reading is noted, for example, 25.05. The slit *P* is then opened, (slit *O* is closed by the same operation) allowing the light reflected from mirror *C'* to pass through the wedge *A* to the selenium cell. The wedge is moved backward or forward before the slit *P* by means of the knob *F* until the galvanometer reading is the same as before, 25.05. This does not indicate that the solution in the part of the wedge penetrated by the light is in equilibrium with the solution in the cell *G*, because of the "drift" of the galvanometer reading, due to the fatigue effect of the selenium cell. It is necessary to again illuminate the selenium cell through the cell *G* and take a second reading. It may be found to have changed, for example, to 25.14. The slit before the wedge is again opened and a slight adjustment is found to be necessary in order to bring it to the same reading. This series of operations is repeated until the cell and the wedge give identical readings. The position of the wedge is then noted on the wedge scale by means of pointer (*t*). For the 0.51% solution this point is 0. (Note: The point 0 is not the extreme end of the wedge but a point on an arbitrary scale. As different scales were used in different phases of the work, the scale readings on different figures are not comparable, but all are centimeter scales.) The other prepared known solutions are then tested in a similar manner with the following results.

% Cu	Wedge Reading
0.77	2.08
1.02	3.85
1.28	5.50
1.53	7.03
1.79	8.75

A calibration curve, Fig. 4, Curve *A*, is made by plotting the percentages of copper as ordinates and the wedge readings as abscissas. Two unknown solutions are then determined in exactly the same manner. Curve *A* shows the percentages of copper by this method and the electrolytic determinations on the same unknowns. Curve *B* shows similar results with copper chloride.

NOTES ON THE METHOD OF OPERATION

The points on the calibration curves were connected point to point. The variations from a straight line are partly due to imperfections in the wedge, and partly to the influence of the fatigue effect.

Percentages are all expressed in grams per 100 cc.

Fig. 4 shows the effect of using different concentrations of copper nitrate in the wedge. With a more dilute solution in the wedge, a longer portion of it corresponds to a definite percent of copper. For sensitiveness, the solution in the wedge should be as dilute as possible.

It is essential that time be allowed for the selenium cell to come to equilibrium before each reading. The difference in the quality of illlumination through the wedge (particularly when an Eastman Neutral Tint Wedge[3] was used) made the fatigue effect very great, especially in the higher concentrations of copper. As a result, readings were very difficult to obtain, due to the inability of the selenium cell to come to equilibrium in a reasonable time. To shorten the time of reading, an experiment was tried in which readings were taken at definite time intervals. The method is the same as that described under Method of Operation, except that the slits are alternately opened and closed every half minute or other suitable time interval. At the same time intervals, the galvanometer readings are noted. Fig. 5 shows that for concentrations up to 0.81% Cu, fifteen seconds is sufficient length of time to allow the selenium cell to come to equilibrium. Quantitative results obtained by "time" readings are shown in Figs. 8 and 9.

Fig. 6 shows that calibration curves made with copper nitrate and with copper sulfate, without changing the solution in the wedge, are very nearly identical.

Fig. 7 shows the effect of placing buffer solutions behind the wedge. (Eastman wedge used in this experiment.) The curves produced are practically parallel. When no buffer is used, the reading for 2.16% copper is near the thick end of the wedge. As the concentration of the buffer solution becomes greater, this reading approaches the thin end of the wedge. The same is true of the other percentages of copper. This suggests that the wedge need not be altered for the determining of the higher percentages of copper. All that is necessary is to place the proper buffer solution behind it.

[3] "Wratten Light Filters" p. 77, fifth edition; 1922, Eastman Kodak Co.

Fig. 8 shows the principle as applied to the quantitative estimation of copper in copper sulfate. If the solution to be tested is so dilute that it transmits more light than the thinnest portion of the wedge, the buffer cell may be placed behind the test cell *G*. Fig. 9 shows the principle as applied to the quantitative estimation of nickel in nickel sulfate. Similar results were obtained with nickel in nickel chloride.

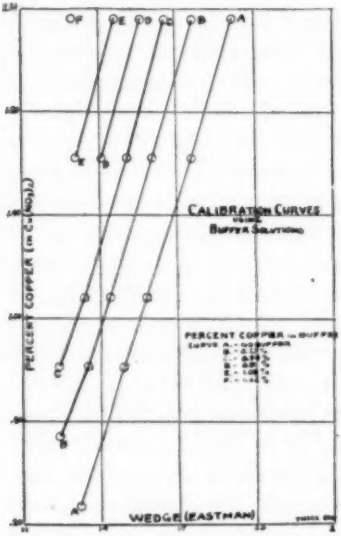

FIG. 7

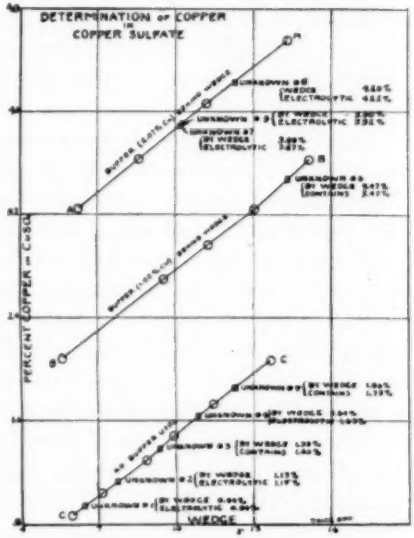

FIG. 8

APPLICATION OF THE METHOD TO MIXTURES

In the work described above C. P. salts were used. George[4] has shown that the absorption of light by a salt in solution is influenced by the presence of another salt, even though the added salt by itself shows almost complete transmission. Considerable work was done with this apparatus in an attempt to discover a means of applying the method to mixtures. It was found that with few exceptions, the addition of a salt or an acid to a copper salt solution (without changing the percentage of copper in the solution) increases the wedge reading to a considerable extent. Spectrophotometer readings show that in all these cases there is an increased light absorption in the red. From the results obtained, it seems that

[4] "The Absorption of Light by Inorganic Salts," Ohio State University, 1920. (Dissertation.)

there may be a possibility of working out quantitative results with the apparatus by the proper control of these factors, but further work is necessary.

LIMITATIONS AND SUMMARY

1. Due to the inherent nature of the selenium cell, the method is applicable only to those solutions whose absorption is in the orange or preferably in the red.

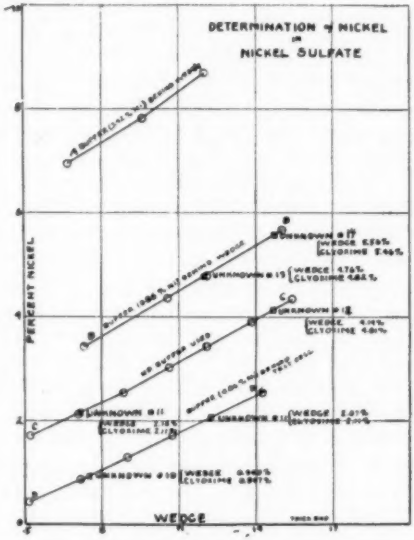

FIG. 9

2. With solutions of C. P. copper nitrate, copper sulfate, copper chloride, nickel sulfate and nickel chloride, quantitative results can be obtained which are in very close agreement with the electrolytic analyses of the copper salts, and the dimethyl glyoxime analyses of the nickel salts.

3. The method is readily used for solutions of low concentration, (up to 2% metal) but in higher concentrations the fatigue effect is so pronounced as to make the determination relatively slow.

4. The presence of other salts and of acids interferes in most cases with the determination, due to an increased light absorption, even when the added material is itself non-absorbing.

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Advanced Practical Physics for Students.—By B. L. Worsnop, B.Sc., and H. T. Flint, M.Sc., Ph.D., Lecturers in Physics, King's College, London and Examiners in Physics, University of London. vi+640 pages. E. P. Dutton and Company, New York. $8.00.

This book is based on laboratory work in Physics given in the Wheatstone Laboratory, King's College, London and developed by the authors and their predecessors "amongst whom we may mention Professors H. A. Wilson, C. G. Barkla, H. S. Allen, W. Wilson, and O. W. Richardson, the present occupant of the chair." There are twenty-four chapters, covering the entire range of classical physics. Each chapter describes a number of experiments under the particular subject. For example Chapter IV, Surface Tension, describes ten different methods of measuring surface tension. In the Chapter on Resistance measurements one finds, in addition to the usual elementary methods, such titles as "The Carey-Foster Method," "The Kelvin Bridge," "The Callendar-Griffiths Bridge," "Calibration and Use of the Platinum Resistance Thermometer," "The Bismuth Spiral," "Determination of the Absolute Resistance of a Metal Rod (Lorentz's Method)," etc.

A feature of the book is the inclusion of a concise but rather complete theoretical treatment of each experiment or instrument "which will enable the student to perform the experiment without immediate reference to theoretical treatises." The introductory section (thirty pages) devoted to the Calculus will be found valuable. One must compliment the authors on the skilful way in which they have thus included a vast amount of theory without unduly extending the book.

The completeness of the list of experiments in the fields covered—the classical physics; for the most part—makes the book useful both for practice work and research. But one is somewhat disappointed in not finding, in a book of this scope, more of the recent developments in apparatus and methods. For example, there is a very excellent chapter on the Dolezalek Electrometer, its construction, theory, and use in a variety of measurements. But there is no mention of the more modern form, the Compton Electrometer, or of that very useful instrument, the Bumstead Electroscope. In the chapter on Photometry, the student is left with the impression that the Kruss rotating wheel is representative of flicker photometers, no reference being made to modern types.

Another fault, rather serious in a book which should be exceedingly valuable for reference purposes, is the omission of a list of references to original sources in connection with the several chapters. Also, the index is by no means complete. One does not find "Electrometer" or "Dolezalek"; but one finds "Quadrant"!

In spite of these minor criticisms, the book is easily one of the most complete and valuable laboratory texts which has yet appeared.

F. K RICHTMYER

MAGNETIC MEASUREMENTS ON MATERIALS OF HIGH INITIAL PERMEABILITY

By P. P. Cioffi

Early in the study of iron-nickel alloys incident to the development of permalloy[1] it became apparent that local strains in toroidal coils of thin tape greatly altered their magnetic properties. It seemed desirable therefore to study the effects of homogeneous strain in samples of simpler form. Straight wires of circular cross-section are, if long enough, suitable for such a study, and thin tapes of rectangular cross-section are almost equally good. Measurements on toroidal specimens in the permeameter which has already been described[2] had yielded very high values of initial permeability. It was clear, therefore, that magnetizing forces ranging from 0 to 10 gauss would be of principal interest, and that cross-sectional areas of less than 0.01 cm^2 would be sufficient for accurate measurements. The apparatus designed under these limitations for the investigation of the effects of strain has proven so useful in this and other connections, and is of so simple a character, that its description will, it is hoped, be of value to other investigators of magnetically soft materials. Aside from its particular application to the study of strain effects it furnished a convenient means for applying and measuring any desired succession of magnetizing processes, and without essential modification lends itself to temperature control over a wide range and to the study of changes due to chemical processes, cold working, and heat treatments.

The principal parts of the apparatus are the magnetizing and search coils, shown in longitudinal section in Figs. 1 and 2. The search coil is short enough with respect to the magnetizing coils to make the correction for the non-uniformity of field within its length entirely negligible. The correction to the total flux change through the coil for that part of the cross-section which is not occupied by the sample depends upon the areas and amounts for samples of the usual dimensions to about 0.45 ΔH, a small correction in the case of the highly permeable materials usually dealt with. The magnetizing coils, of which there are two, and the sample itself,

[1] H. D. Arnold and G. W. Elmen, Frank. Inst., J. *195*, pp. 621-632; 1923.
[2] G. A. Kelsall, J.O.S.A. & R.S.I., *8*, pp. 329-338; 1924.

are made long to minimize end-corrections. With a circular wire 0.1 cm in diameter and 60 cm long, which may be taken as representative, the dimension ratio (length/thickness) is 600, and the

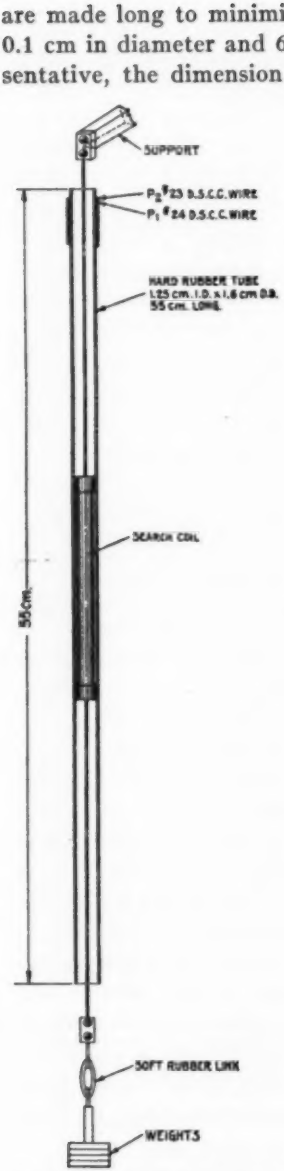

FIG. 1. *Magnetizing and search coils, and means of applying tension to specimen.*

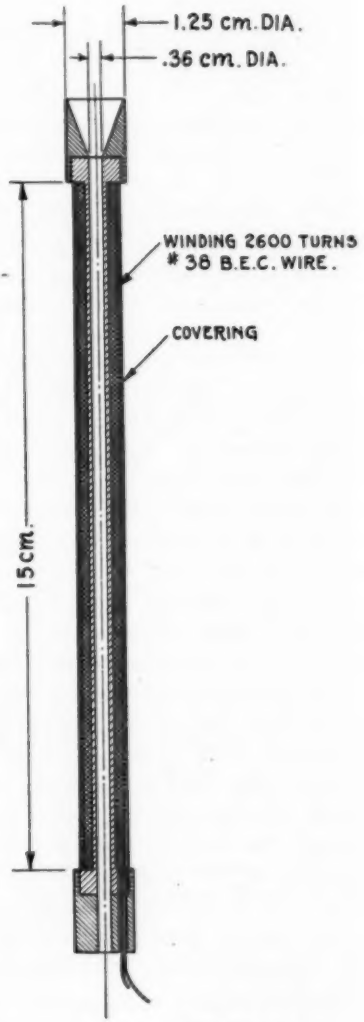

FIG. 2. *Search coil.*

difference between the applied field and that existing within the sample is approximately $B \times 10^{-5}$ for moderate values of B. This latter correction is somewhat uncertain, as it has not been applied

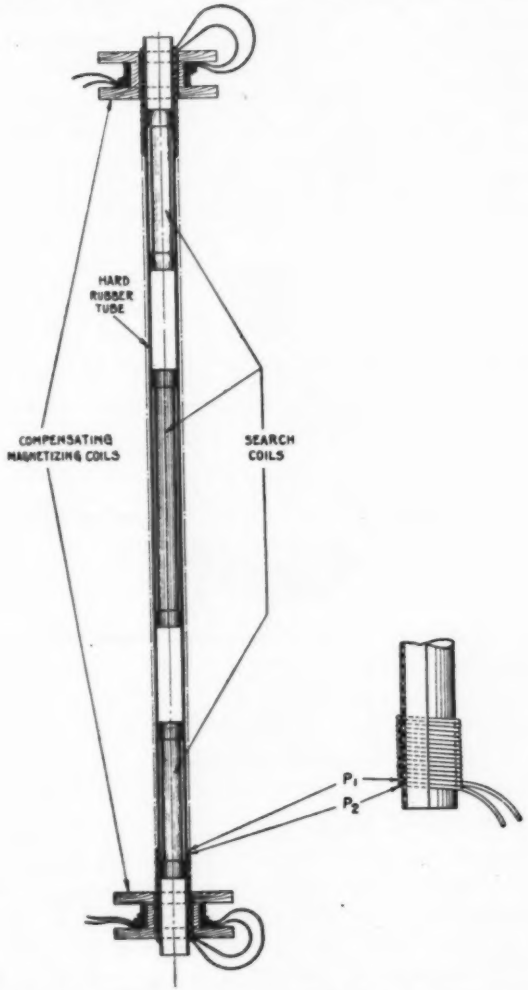

FIG. 3. *Special arrangement for measuring distribution of flux along specimen.*

to the data shown in Figs. 6 and 7. Its effect would be to make the steepest parts of the curves practically vertical. The values of B

and H at all points within that part of the sample lying within the search coil were computed to differ from their values at the center by less than 3%. Errors of this magnitude in absolute values of B and H are rarely of importance. Relative values for a single sample or for similar samples not differing too much in magnetic behavior can, of course, be measured with far greater accuracy. This computed uniformity was checked experimentally by the temporary use of extra magnetizing and search coils arranged as shown in Fig. 3. A convenient feature of the single-layer magnetizing coils was the choice of such a pitch of winding that the field strength in gauss was just ten times the magnetizing current in amperes.

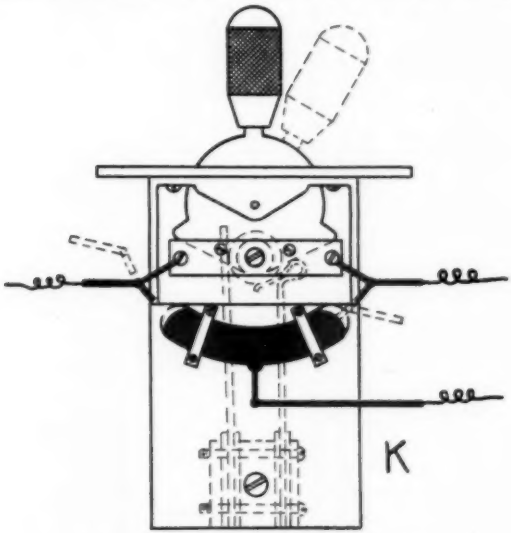

FIG. 4. *Galvanometer circuit mercury switch.*

In direct current measurements the changes in magnetization due to a sudden change in magnetizing field is measured by the deflection of a ballistic galvanometer, the transverse dimensions of the sample being so small that the time required to establish the final state is small compared to the period of the galvanometer. The maximum sensitivity attainable in the present apparatus is about 50 mm/maxwell, and lower sensitivities are conveniently obtained by inserting resistance in series with the galvanometer and search coil. The galvanometer circuit is protected as fully as

possible against thermoelectric currents by screening all its junctions from drafts and by using mercury contacts in the galvanometer key. This key, shown in Fig. 4, also permits the galvanometer coil to be brought to rest before connecting it to its circuit. Unless this is done the current generated by the galvanometer coil when coming to rest magnetizes a carefully demagnetized sample. The galvanometer is calibrated by reversing known currents in the primary of an aircore mutual inductance the secondary of which is permanently connected in the galvanometer circuit. Calibration must, of course, be effected without magnetic materials in the search coil.

TABLE 1

Explanation of Symbols used in Figs. 5 and 8.

C_s	Search Coil
P_1, P_2	Magnetizing coils
P_c, C_c	Calibrating induction coil, wooden core, mutual inductance 0.05 Henry
G	Leads and Northrup high sensitivity ballistic galvanometer, model 2285-d, with 12-ohm coil and concave mirror, used with lamp and scale No. 2105, scale distance 120 cm (Julius Suspension)
K	Western Electric Key No. 479 C, used as mercury switch
A_1, A_2	Direct current milliammeters
A_3	Alternating current ammeter
I	Inductometer
T	Low impedance telephone head-set
T_1, T_2	Vacuum thermocouples
A, A'_2	Direct current microammeters
P'_c, C_c	Variable mutual inductance

In all magnetic researches the attainment of definite initial conditions is absolutely essential, and the easiest way of ensuring definiteness in this respect is to carry the material to saturation with an alternating magnetizing force which can then be reduced gradually to zero amplitude. Means are accordingly provided for applying such a "demagnetizing" current in one of the magnetizing coils while maintaining the current in the other at any desired value. With the materials principally studied H_{max} needs to be only about 10 gauss to ensure anhysteretic conditions, but momentary values as high as 50 can be used without damaging the apparatus.

The details of the actual set-up are sufficiently indicated by the circuit diagram, Fig. 5, and by the explanations in Table 1. It will be noted that the magnetizing current in one of the magnetizing coils may be varied suddenly between any two values, positive or negative, by suitable choice of the resistance R_1, R_1' and R_1'' and by appropriate manipulation of the switches S_1 and S_1'. A third

value may be reached by control, at S_5 of the current through the other magnetizing coil. The use of a suitable telephone key for this switch proved especially convenient. The flexibility of control over the magnetizing current permits a wide variety of experiments to be performed. In determining hysteresis loops, for example, two of the three chosen values being fixed at the ends of the loop, the third is varied to cover the intervening range. Figs. 6 and 7 illustrate experiments made in this manner upon tapes of permalloy

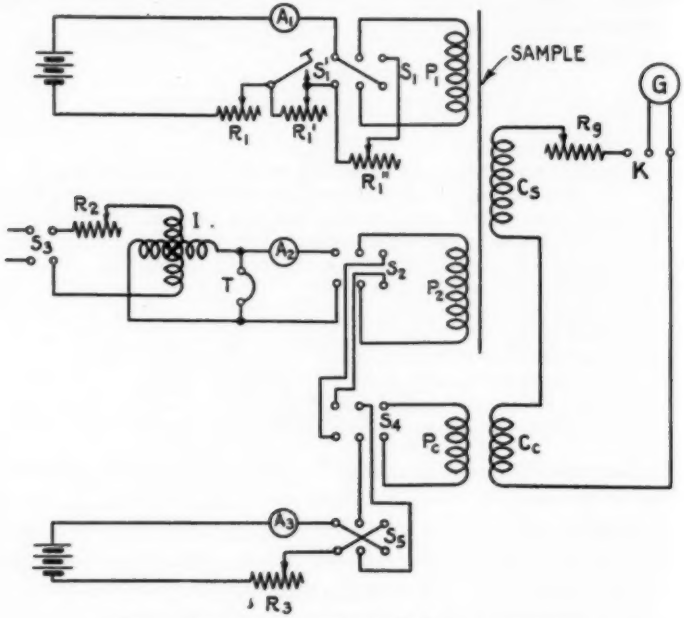

FIG. 5. *Diagram of connections for ballistic measurements.*

(not of the highest initial permeability), 0.015 cm thick and 0.32 cm wide. Fig. 6 corresponds to the case in which the sample is demagnetized in zero applied field before each magnetization, Fig. 7, to the case in which, after a single careful demagnetization, cyclic conditions are established by many repetitions of the same hysteresis loop between each pair of readings.

Alternating current measurements have also been made upon the same samples in the same magnetizing and search coils. The necessary modifications in the apparatus are indicated in the circuit

diagram, Fig. 8 and in Table 1. The amplifier and thermocouple T_1 used in measurement are calibrated as a unit by a current through P_c' equal to that used for magnetization, and derived from

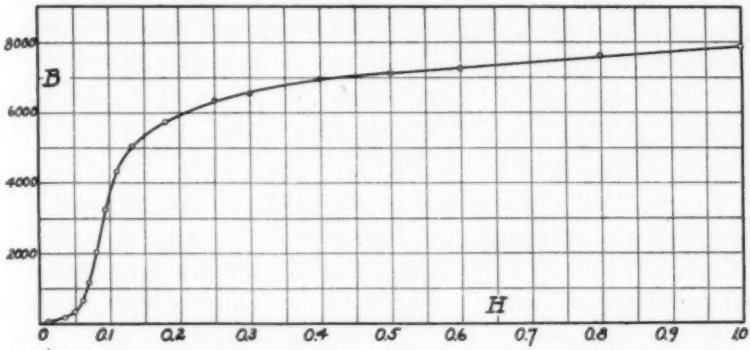

FIG. 6. *Normal magnetization curve for permalloy tape with 78.5% nickel and 21.5% iron.*

the same vacuum tube oscillator. Interference due to amplifier pick-up and capacity coupling between the various elements is greatly reduced by completely shielding the amplifier and other parts of the circuit.

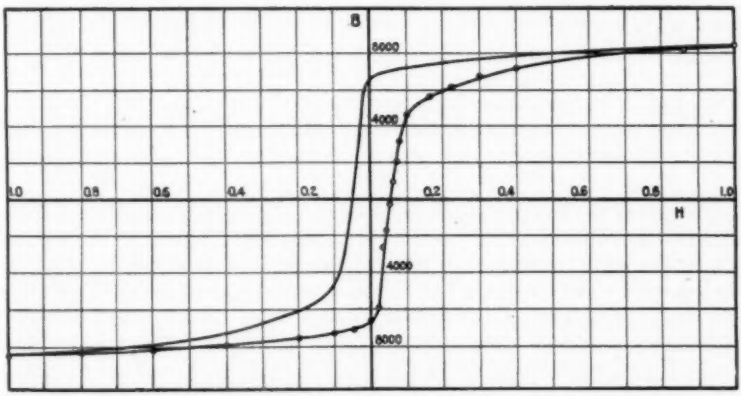

FIG. 7. *Hysteresis loop for permalloy tape with 78.5% nickel and 21.5% iron.*

In order to facilitate the application and measurement of tension the apparatus is so arranged that the samples hang vertically between links to prevent bending stresses, and are stretched by weights on a scale pan hung at the lower end. Variations in tension

due to jarring of the support may be minimized by making the lower link of soft rubber washers. The weights are applied and removed by hand, the maximum total load which has to be used being less than thirty pounds. Change in tension is usually accompanied by change in magnetization[3] so that care must be taken to make changes in conditions in the proper sequence.

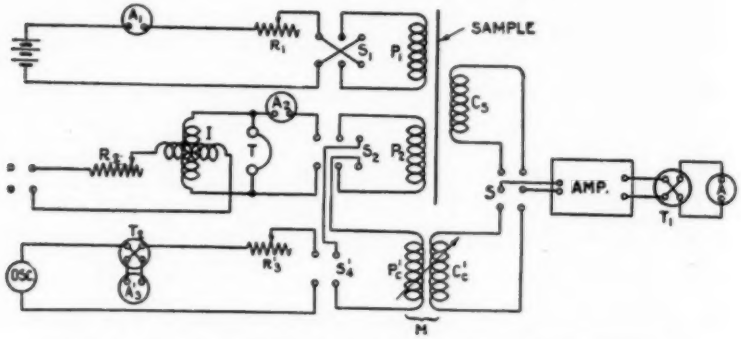

FIG. 8. *Diagram of connections for alternating field magnetic measurements.*

The removal and replacement of samples is so easy that apparatus of the same type but without such a variety of controls has been found very convenient in the routine testing of permalloy tape for magnetic quality.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH COMPANY
AND THE WESTERN ELECTRIC COMPANY, INCORPORATED.
DECEMBER 17, 1923.

Relation between the initial Energy of Alpha Particles and the Atomic Number of the Nucleus which emits Them.—Myssowsky plots the initial energies of the alpha particles emitted by nineteen radioactive nuclei against the atomic number of the emitting nucleus, and finds that three of the points lie on a descending straight line, five others on a second and four others on a third, all three lines being parallel and equally spaced. Five points lie quite off these lines, and it may be significant that four of them belong to elements at which a branching of the series occurs. The data for a twentieth element (Th) are too uncertain.—[L. Myssowsky (St. Petersburg); ZS. f. Phys. *18*, pp. 304-306; 1923.]

K. K. DARROW

[3] L. Fraichet, Rev. de Met., *20*, pp. 32-45; 1923.

A PORTABLE GLARIMETER

By G. A. Shook

The instrument described herein is a modified form of the apparatus developed by Jones[1] for the determination of gloss in the case of photographic papers. By simplifying the optical system and by reducing the entire apparatus to small dimensions a portable instrument requiring no auxiliary apparatus was finally produced. As it measures only 8x6x2½ in. it is very convenient for determining the glare of walls, etc.

The specimen to be examined is illuminated by a parallel beam of light incident at an angle of 45° and the relative brightness of the light specularly reflected at 45° and that diffusely reflected at 0° is taken as a measure of the glare.

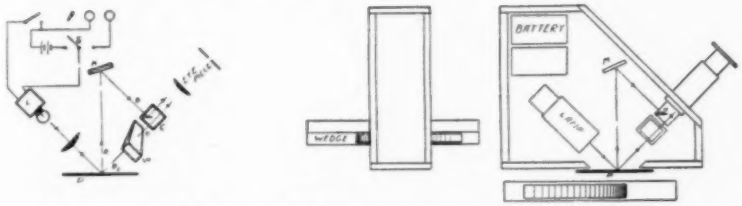

Fig. 1. *A portable glarimeter of small dimensions*

In Fig. 1 let the brightness of the light reflected at 45° be B_2 and that reflected at 0° be B_1 then the glare is defined by the equation

$$G=\frac{B_2-B_1}{B_1}$$

In the apparatus used by Jones a lens is inserted in the path of B_1 so that an image of the paper, under test, is formed in the photometric cube. The same is true for B_2. For a paper having a considerable amount of glare however, the two halves of the photometric field will not appear the same; the image due to the diffusely reflected light being uniform while that due to the specularly reflected light will be more or less mottled. This effect may be diminished by throwing the latter image out of focus but in the instrument under consideration these lenses are omitted so that both halves of the field will always be uniform. This does not mean

[1] L. A. Jones, Jour. Opt. Soc. Am., *2*; 1922.

however that this portable instrument is, on the whole, more accurate than the apparatus developed by Jones. Its advantage lies in its portability and its simplicity of construction.

The general arrangement of the optical and electrical parts of the glarimeter is shown in Fig. 1 and also a diagram of the actual instrument with cover removed. The incident parallel beam of light is formed by a 2.5 volt battery lamp placed at the principle focus of a lens. The lens is 1½ in. focus and 1 in. in diameter. The current may be obtained from two small cells within the instrument or when convenient an outside source may be used. This is controlled by the switch S.

The diffused light B_1 is reflected from the mirror M to the silvered face of the photometric cube C and thence to the eyepiece. The specularly reflected beam B_2 passes through a neutral tint wedge, which is used to vary the brightness, and then through the cube as shown. An eyepiece with a focal length of 1¾ in. provided with a ⅛ in. aperture 2 in. from the lens, is used to examine the cube C.

The wedge used here is so constructed that at any point along its length

$$\text{Density} = \log \frac{1}{\text{transmission}} = nR$$

where R is the distance in centimeters from this point to the point of maximum transmission and n is a constant. For a wedge whose maximum density is 1, n is 0.1 and for one of density 2 it is 0.2, etc.

In order to determine the glare of a given sample it is necessary to have some sort of a test surface such as a block of magnesium carbonate which has practically no glare. Suppose such a block is placed at P, then $B_2 = B_1$ and if the reflection factor of the mirror M is ρ, $B = \rho B_1$.

Let the reading of the wedge be R_0, when a balance obtains under these conditions. From the law of the wedge

$$\log \frac{B_2}{B} = \log \frac{B_1}{\rho B_1} = nR_0$$

If the test surface is replaced by the sample to be measured then

$$\log \frac{B_2}{\rho B_1} = R$$

therefore

$$\log \frac{B_2}{B_1} = n(R - R_0)$$

from which G may be calculated.

In measuring colored specimens the specularly reflected light is of course more saturated than the diffusely reflected light and this makes it difficult to obtain an accurate setting. For testing and controlling the uniformity of a given product, say a particular type of paper, a colored glass may be used and moreover the glass need not be the same color as the paper. Two different colored glasses however will not of course give the same reading for a given colored paper.

That is, if one observer uses a blue glass and another a yellow glass for the same surface the two results cannot be compared and moreover neither result necessarily represents quantitatively the subjective glare effects which may occur under conditions of use. The value thus obtained is merely a measure of the glare, as defined above, and must be considered thus.

In general readings made with a colored glass are of value only when the color of the surface under consideration is constant.

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Free Paths of Electrons in Gases.—Minkowski and Sponer have developed a comparatively simple method for determining whether a particular gas displays the curious effect which Ramsauer lately discovered in argon—that is, a very marked increase in the mean free path of electrons in the gas as the electron speed is decreased from about 5 volts towards zero. In an ordinary three-element cylindrical tube they apply an electron-accelerating voltage between grid and filament, the space between filament and plate being almost field-free. The plate current, in an evacuated tube, rises as the 3/2 power of the voltage; in a tube containing a gas in which the electron mean free path is independent of electron speed, it should rise steadily but more slowly, for the electrons, owing to their collisions with atoms and the zigzag paths which these cause them to describe, remain longer in the space between filament and plate, and produce an extra space charge effect. But if the tube contains a gas in which the electron mean free path is very large at (say) 1 volt and diminishes rapidly as the electron speed is increased, this extra space charge effect will at first be small and then will become rapidly larger; the curve of plate current versus grid voltage will be distorted, and may even present a sharp maximum at a low value of voltage. Such a maximum was discovered in the gases A, Kr, and Xe. In the curves for Ne and He slight roughnesses were observed which were taken as indications of a comparatively slight effect of the same nature. Minkowski presents additional curves for Hg and for Cd vapors in his latest paper, and they show unevennesses

which also indicate a relatively slight variation of electron mean free path with electron speed. At values of V slightly in excess of resonance potential, some of the electrons lose almost their entire energy in inelastic impacts and become slow electrons. This tends to increase the space charge effect; on the other hand, the augmented free path tends to decrease the space charge effect. In the gases A, Kr, and Xe the latter influence is the stronger, and the curves suddenly shoot upwards at the resonance potentials. Sponer attempts to determine whether this upward slope is greatest at the resonance potential exactly, or at a perceptibly higher voltage; if the latter, then the mean free path of the electrons must have a maximum value at a speed appreciably greater than zero. To do this she located the resonance potential for argon by using Hertz' method, and concluded that it agreed with the voltage at which the upward slope of the plate current curve is greatest, within a tenth of a volt. Sponer also locates two resonance potentials in Kr and two in Xe by her method. In such gases as Hg and Cd vapor, however, the space charge effect increases at the resonance potentials instead of decreasing, so that these potentials show themselves in the curves as points of downward bending instead of upward slopes. [R. Minkowski and H. Sponer, ZS. f. Phys. *15*, 399-409; 1923. R. Minkowski, ibid. *18*., pp. 258-262; 1923. H. Sponer, ibid. 1923. R. Minkowski, ibid. *18*., pp. 258-262; 1923. H. Sponer, ibid. *18*., pp. 249-257; 1923]. K. K. DARROW

Radiation Potentials of Atomic Hydrogen.—A tube consisting of a cylinder of tungsten foil stretched between heavy metal end pieces contains a hollow cylinder enclosing an oxide coated pointed platinum wire, and a metal disc opposite the open end of the hollow cylinder. The tube is heated to 2800° K by an intense current through the tungsten foil, which dissociates the hydrogen contained in it and heats the oxide-coated wire enough for it to emit quantities of electrons. These are accelerated to the hollow cylinder, and the radiation emitted by the struck hydrogen atoms is detected by its photoelectric effect on the disc; various gauzes and metal screens serve to keep ions from reaching the disc and to draw photoelectrons away from it. Radiation potentials are determined, as usual, by looking for "breaks" on the curve representing photocurrents as a function of electron-accelerating voltage. On their best curves the authors discern seven breaks which they associate with the first six lines and the convergence-frequency of the Lyman series. It is not clear how great the accuracy of location of the breaks is considered to be. The break corresponding to the first Lyman line is less conspicuous than that corresponding to the second; this is taken to mean that quanta of this radiation are especially liable to be reabsorbed and scattered.—[P. S. Olmstead and K. T. Compton, Princeton; Phys. Rev., (2) *22*, pp. 559-565; 1923].

K. K. DARROW

PORTABLE UNSATURATED WESTON CELLS

By Warren C. Vosburgh and Marion Eppley

Unsaturated Weston cells are widely used as working standards of electromotive force on account of their low temperature coefficient. If a cell is to be satisfactory for this purpose variation in electromotive force due to room temperature fluctuations and changes over fairly long periods of time should together amount to not more than 0.02%, since many potentiometers are accurate to this degree. In order that the cells may be shipped from maker to user, or to the Bureau of Standards for certification, they must be made portable so that shaking or turning up side down will not mix the contents or alter the electromotive force.

The authors[1] have found the temperature coefficient of non-portable unsaturated Weston cells to vary between 3 and −13 microvolts per degree over the range of cadmium sulfate concentrations studied. Such cells were found to have very little hysteresis with changing temperature. However, it has been found that portable cells often behave differently from non-portable ones, especially with respect to hysteresis. Therefore it was undertaken to investigate the factors causing the difference and to determine how portable unsaturated cells can be made with the highest degree of constancy.

A number of devices for making standard cells portable have been described.[2] The device adopted was similar to that originally used by Weston,[3] and described also by Tinsley[4] and by Rodman and Spooner,[2d] in which the mercury and mercurous sulfate were held in place by a cork disk. This has the advantage of simplicity, of allowing a simple form of vessel to be used, and of allowing the cells to be hermetically sealed. The possibility of introducing interfering impurities is not greatly to be feared since the corks can be previously treated to remove impurities, and small amounts of most impurities are not likely to affect the electromotive force greatly.[5]

[1] Vosburgh and Eppley, J. Amer. Chem. Soc., *45*, p. 2268; 1923.

[2] (a) Laws, Electrical Measurements, McGraw Hill Book Co., New York, p. 300, 1917. (b) De Lury, Phys. Rev., *25*, p. 492; 1907. (c) Cohen and Kruyt, Z. Physik. Chem., *72*, p. 38; 1910. (d) Rodman and Spooner, Trans. Am. Electrochem. Soc., *38*, p. 99; 1920.

[3] Electrician, *30*, p. 741; 1892.

[4] Tinsley, Electrician, *65*, p. 568 (1910).

[5] (a) Steinwehr, Z. Electrochem., *12*, p. 579; 1906.
(b) Hulett, Phys. Rev., *32*, p. 259; 1911.

PREPARATION OF CELLS

The cells of this investigation were set up in vessels of the H type 11 cm long by 6 cm wide with tubes of 1.4 cm diameter. Some electrolytically prepared 12.5% cadmium amalgam, sufficient to cover the sealed-in platinum wire, was placed in one leg of the tube, mercury which had been redistilled in a current of air[6] was placed in the other leg, and both were covered with some nearly saturated cadmium sulfate solution which contained a small amount of sulfuric acid. Mercurous sulfate paste was placed on top of the mercury in a layer about 1 cm deep. Then a cork disk with a hole in the center and with a piece of linen cloth under it and between it and the wall of the tube was pushed down on top of the paste to hold the mercury and paste tightly in place. A similar cork and

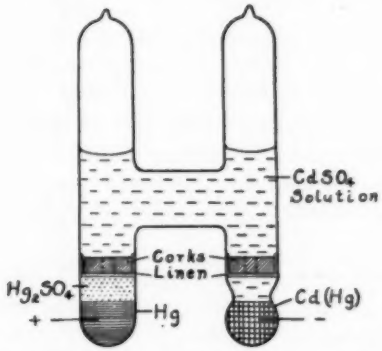

FIG. 1. *Construction of a portable unsaturated Weston Cell.*

linen septum was pushed down over the amalgam, but not tightly. Cadmium sulfate solution was then run in to a level above the cross arm and the cells were hermetically sealed. It was found that the portability of the cell could be improved by mixing asbestos such as is used for Gooch crucibles with the mercurous sulfate and by making small dents in the glass tube just above where the cork was to rest. The anode leg of the tube was constricted just above the amalgam, and with a 12½% amalgam no trouble was experienced in its getting loose. The arrangement of the materials in a complete cell is shown in Fig. 1.

[6] Hulett, Phys. Rev., *33*, p. 307; 1911.

HYSTERESIS IN PORTABLE CELLS

A number of portable cells were made in this fashion from the purified materials prepared for the previous study of unsaturated Weston cells.[1] The corks and linen used were purified by extraction with successive portions of boiling water, the former being treated until very little colored matter was extracted. A comparison of these portable cells with similar non-portable cells showed a very large difference in the hysteresis. It had been found that the non-portable cells showed practically no hysteresis when the temperature was changed from 35° to 25°. On the other hand the portable cells showed a hysteresis under the same conditions which in some cases amounted to 0.1% of the value of the cell. When the temperature dropped, the electromotive force rose to an abnormally high value and decreased slowly, sometimes requiring over a month to attain a constant value again. Some typical results are shown in Table 1. The hysteresis was measured when the cells were 5 months

TABLE 1. *Hysteresis in Portable Unsaturated Weston Cells.*

Cells[a]	Emf 35° v.	Hysteresis 1 hour Mv.	6 Mv.	24 Mv.
11515	1.01869	>1.31	>1.31	1.31
11516	1.01869	1.26	0.99	0.78
11517	1.01867	0.50	.35	.26
11518	1.01871	.44	.34	.26
11519	1.01875	.39	.27	.19
11520	1.01865	>1.35	>1.35	1.22

[a] The electrolyte in these cells contained 0.0115 moles of sulfuric acid in a liter.

old in the manner previously described.[7] The cells were maintained at 35° in an oil bath until equilibrium was assured, then they were transferred to another bath at 25° and measured after the intervals given by means of the potentiometer described by Eppley and Gray[8] and the standards described by Vosburgh and Eppley.[9] The difference between the abnormal electromotive force after the temperature change and the equilibrium value at 35° was taken as a measure

[7] Vosburgh and Eppley, J. Am. Chem. Soc., *46*, p. 109; 1924.
[8] Eppley and Gray, J. O. S. A. & R. S. I., *6*, p. 859; 1922.
[9] Ref. 7, p. 106.

of the hysteresis.[10] The results in Table 1 make it evident that even 24 hours after a pronounced temperature drop cells such as Nos. 11515-11520 would be unreliable for accurate work.

The variability of the hysteresis in cells apparently made in the same way is illustrated in Table 1. The only difference in construction was the soaking of the corks used for Cells 11519-11520 in melted paraffin.

Although a decrease in temperature caused an abnormal electromotive force an increase had no such effect. Even when cells with the abnormal electromotive forces resulting from a temperature drop were brought back to the higher temperature again the electromotive forces at the higher temperature were the normal ones. Table II shows the results of such an experiment with Cells 11515-11519 which was carried out 11 months after the hysteresis test of Table I. The cells were first brought practically to equilibrium at 25°, then they were transferred to a bath at 35° and kept four days. After the first day at 35° the electromotive forces varied not more than 0.007 *mv*. They were then transferred back to the bath at 25°, kept there one day, and measured. Then they were kept at 35° for one day and measured, transferred back to the bath at 25° and measured a day later, and so on as shown in Table 2. The quantities in the 4th to 9th columns of the Table are the differences between the electromotive forces under the conditions specified and the equilibrium electromotive forces at the same temperatures.

The results in Table 2 show that with such cells under varying temperature conditions the measurements at the highest temperature attained are free from errors due to hysteresis, while measurements at lower temperatures made after a drop in temperature are in error to a greater or lesser degree.

In newly made cells the hysteresis was generally very low but increased considerably during the first few months. For this reason hysteresis results for different cells were considered comparable only if the tests had been made when the cells were the same age, and all cells were tested when 5 months old. However,

[10] Generally the equilibrium electromotive force at 25° was used in calculating the hysteresis. In these cells such a long time was required for the attainment of equilibrium that reliable values at 25° were not obtained at the time of the test. The temperature coefficients were small, however, and the electromotive forces 25° and 35° must have been nearly equal. See Table 2.

comparison of Tables 1 and 2 shows that the hysteresis has decreased in the cells showing the most hysteresis and increased only a little in the others during the interval between the two experiments. Therefore no large increase in the hysteresis of cells is to be expected after the cells are 5 to 6 months old.

A slight decrease in electromotive force with time is indicated by the results in Tables 1 and 2. Comparison of the two sets of values at 35° indicates an average decrease of 0.04 mv or 0.004% during

TABLE 2. *Effect of Fluctuating Temperature on the Electromotive Force*

Cells	Emf 25° v.	Emf 35° v.	Increase in emf due to temperature change					
			1st day 25° Mv.	2d 35° Mv.	3d 25° Mv.	4th 35° Mv.	5th 25° Mv.	6th 35° Mv.
11515	1.01868	1.01865	1.13	0.01	1.15	0.01	1.16	0.00
11516	1.01869	1.01867	0.67	.00	0.69	.00	0.70	.01
11517	1.01865	1.01859	.30	.00	.30	−.01	.31	.00
11518	1.01865	1.01864	.36	−.01	.36	−.01	.37	.00
11519	1.01878	1.01873	.38	.00	.39	.00	.40	.00

the 11 months intervening between the two sets of measurements.[11] The decrease can be explained on the basis of diffusion of mercurous sulfate and its reaction with cadmium, resulting in an increase in cadmium sulfate concentration in the electrolyte.

EFFECT OF ACIDITY OF THE ELECTROLYTE ON HYSTERESIS

Since an increase in the acidity of the electrolyte of non-portable normal Weston cells decreased the hysteresis very appreciably,[12] the effect of varying the acidity in portable unsaturated cells was tried. A number of cells were made of purified materials[13] and similar in every respect except in the acidity and concentration of cadmium sulfate of the electrolyte.[14] Different electrolytes were prepared by saturating dilute sulfuric acid solutions with hydrated cadmium sulfate at 25° and slightly diluting the saturated solutions

[11] The cells were kept at room temperature during this time.

[12] Ref. 7, p. 110.

[13] The cadmium sulfate was recrystallized, the mercury was redistilled in a current of air at reduced pressure, the amalgam was prepared by transferring cadmium electrolytically from sticks of commercial cadmium to the mercury, and the mercurous sulfate was prepared electrolytically.

[14] The solubility of cadmium sulfate is dependent on the acidity of the solution.

with the acid solution. The resulting acid concentrations, given in Table 3, were calculated approximately from the known concentrations of the acid solutions and the volume change on saturating with hydrated cadmium sulfate as determined by Hulett.[15] Five cells were prepared with each cadmium sulfate solution. The cells were allowed to stand for 5 months before the final measurements were made. The hysteresis was measured as described above, the cells being previously maintained at 35° for four days. The equilibrium values at 25° were used in calculating the hysteresis. The results are shown in Table 3, average results for groups of 5 cells each being given.

TABLE 3. *Effect of Acidity of the Electrolyte on Hysteresis*

Cells	Acidity of Solution Moles per liter	Emf[a] 25 v	Hystersis 1 hr. Mv	5 Mv	24 Mv
12336–40	0.014	1.01880	0.58	0.46	0.35
100–104	.023	1.01869	.30	.24	.19
105–109	.030	1.01859	.24	.17	.11
110–114	.038	1.01860	.08	.05	.03
115–119	.046	1.01847	.05	.04	.03
120–124	.053	1.01864	.06	.03	.02
163–167	.076	1.01875	.05	.04	.03

[a] The average variation from these values was 0.03 mv.

The effect of acidity of the electrolyte on hysteresis is shown by plotting the results in Tables 1 and 3. The curve so obtained is given in Fig. 2. The hysteresis is greatly reduced by an increase in acidity up to an acidity of about 0.04 moles per liter but beyond that point an increase in acidity has little effect. Although these results are only approximate on account of the large differences between individual cells illustrated in Table 1, the change in hysteresis with acidity is larger than the uncertainty in the results.

The cork in a portable cell seems to have some effect on the composition of the solution. Some cells made like those of Table 1 but with the corks about 6 mm above the top of the mercurous sulfate layer showed about as much hysteresis as Cells 11518 and 11519. Adsorption of some of the acid by the cork is not a satisfactory explanation since non-portable cells with neutral electrolytes do not show as much hysteresis as portable cells made with acid

[15] Hulett, (a) Trans. Am. Electrochem. Soc., *14*, p. 76; 1908. (b) Phys. Rev. *27*, p. 350; 1908.

electrolytes. Other effects of the cork on the composition of the electrolyte are possible but owing to the complicated nature of the cathode system of the Weston cell no satisfactory explanation seems possible at the present time.

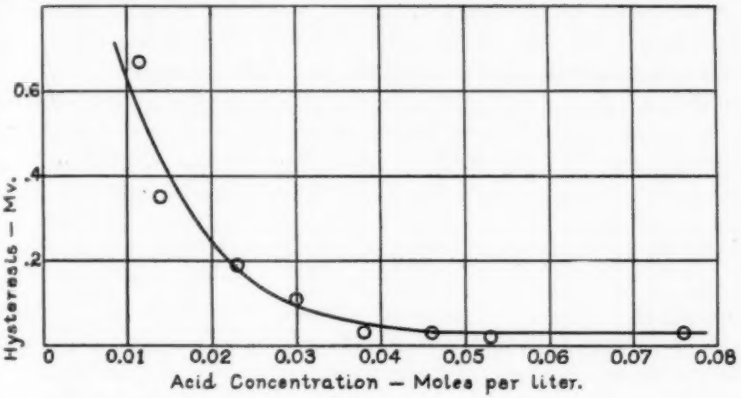

FIG. 2. *Variation of the hysteresis with the concentration of acid in the electrolyte.*

EFFECT OF THE GRAIN SIZE OF THE MERCUROUS SULFATE ON HYSTERESIS

The authors[7] have shown that normal Weston cells made with fine gray mercurous sulfate show less hysteresis than those made with coarser mercurous sulfate. The cells described so far were made with mercurous sulfate prepared electrolytically and digested with a sulfuric acid solution on a hot plate to increase the grain size. Some additional cells were made with finely divided mercurous sulfate prepared by the reduction of mercuric sulfate by mercury.[16] A hysteresis test on these cells when they were 5 months old gave the results shown in Table 4.

When finely divided mercurous sulfate is used an acidity of 0.03 moles per liter is sufficient to reduce the hysteresis to practically zero. The effect of the grain size on hysteresis must be due to its effect on diffusion. The reattainment of equilibrium in a cell with coarse mercurous sulfate is evidently a slow process. If it is dependent either on the catalytic action of mercury on a reaction taking place in the solution[17] or on a reaction between mercury and solution,

[15] The preparation designated as mercurous sulfate No. 6 in a previous paper. (Ref. 7).
[17] See Hulett, Ref. 15a, p. 85, Ref. 15b, p. 358.

such as the reduction of mercuric ions, the time required for the attainment of equilibrium would depend on the rate of diffusion of substances in the solution to the mercury. If diffusion were very slow a condition of local equilibrium near the mercury electrode would be set up quickly and the cell would have small hysteresis. It follows also that the presence of finely divided mercury in the mercurous sulfate paste would tend to reduce hysteresis.[7]

TABLE 4. *Hysteresis in Cells made with Fine Mercurous Sulfate*

Cells	Acidity of Solution Moles per liter	Emf[a] 25° v	Emf 35° v	Hystersis 1 hour Mv	5 Mv	24 Mv
198–202	0.020	1.01891	1.01887	0.08	0.04	0.01
203–207	.029	1.01899	1.01895	.01	.00	−.01
208–212	.039	1.01906	1.01902	.00	.00	−.01
213–217	.048	1.01907	1.01903	−.01	−.01	−.01

[a] The average variation from these values was 0.05 mv in the first group and 0.01 mv in the other groups.

When asbestos is mixed with the mercurous sulfate the hysteresis is increased a little, as might be expected from the relation of hysteresis to the chances for diffusion. However, the effect on the hysteresis is small while the portability of the cell is greatly increased. In the cells described above usually about 0.05 g of asbestos per cell was mixed with the mercurous sulfate. In a group of cells otherwise duplicates of Nos. 198-217, Table 4, five times as much asbestos was used. The hysteresis 1 hour after the temperature change varied between 0.05 mv and 0.08 mv.

TEMPERATURE COEFFICIENTS

Calculation of the temperature coefficients of electromotive force from the data in Tables 2 and 4 shows that they have larger negative values than the temperature coefficients of non-portable cells of the same electromotive forces.[18] Cells of the same group did not agree among themselves as well as a group of non-portable cells. It is therefore to be concluded that the device used to make the cells portable has a small effect on the temperature coefficient. The temperature coefficients were in no case large enough to be of any great importance however. The largest among cells 198-217 was −6 microvolts per degree, which would cause a change of 0.01% in

[18] See Ref. 1, p. 2274.

the value of the cell for a 15° temperature change. It is to be expected that the temperature coefficients could be reduced in magnitude by the use of a more concentrated cadmium sulfate solution.[18]

PORTABLE NORMAL CELLS

It is to be expected that portable normal cells would behave like portable unsaturated ones. It has been found that the hysteresis is greatly reduced by an increase in the acidity of the electrolyte. For a given acidity it is of the same order of magnitude as in unsaturated cells. There is, however, a complicating factor in the lag in solution and precipitation of cadmium sulfate which with a temperature drop causes an opposite effect to that observed in the unsaturated cells. Thus, when the acidity is sufficiently great the first effect of a temperature drop on the electromotive force may be to cause an abnormally low value. The condition of equilibrium with respect to the cadmium sulfate concentration is quickly reached, however, in properly constructed cells, and after the first few hours only the type of hysteresis exhibited by the unsaturated cells is noticeable.

SUMMARY

1. Portable unsaturated Weston cells showed much greater hysteresis with a decrease in temperature than similarly constructed non-portable cells.

2. The hysteresis decreased with increase in the concentration of sulfuric acid in the electrolyte and with a decrease in the grain size of the mercurous sulfate. With finely divided mercurous sulfate and an electrolyte of sufficient acidity cells were prepared which showed practically no hysteresis.

3. The temperature coefficients of the portable cells were negative and numerically larger than those of non-portable cells of the same electromotive forces, but were negligible for practical purposes.

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NEWPORT, R. I.

X-ray Absorption Coefficients as Functions of Wave Length and Atomic Number.—Richtmyer and Warburton measure the absorption coefficients of Fe, Co, Ni, and Cu (elements 26, 27, 28, 29) over the wave length range from .12 to .30A (the *K*-absorption wave lengths of all four metals being much greater than .30A), and find that each is quite accurately a straight line function of λ^3. At any one wave

length the absorption coefficient increases with the atomic number of the metal. Since in this group of metals the order of atomic weights deviates from the order of atomic numbers the result is especially important. The absorption coefficient for a given number of atoms (i.e. the quotient of the mass absorption coefficient by the number of atoms per unit mass) is plotted against the fourth power of atomic number; the values for Co, Ni and Cu fall on a straight line, but the value for Fe drops below the line by an amount exceeding the supposed uncertainty of experiment. However, Richtmyer and Warburton present data for six additional elements, the set of ten extending from atomic number 6 to atomic number 82; the linear relation between atomic absorption coefficient and fourth power of atomic number seems very well substantiated over this wide range.—[F. K. Richtmyer and F. W. Warburton, Cornell, Phys. Rev., (2) *22*, pp. 539-545; 1923].

K. K. DARROW

Energy of the K-radiations from Cr (24), Cu (29), Rh (45), and Ag (47).—Unnewehr measured the intensity of the (unresolved) $K\alpha$-line, of the $K\beta$-line, and of the general radiation at wave lengths on both sides of these lines; he interpolated to obtain a value for the intensity of general radiation at the frequency of each line, subtracted this quantity from the observed intensity of the line, and regarded the difference as the measure of the true intensity of the characteristic $K\alpha$ and $K\beta$ radiations. The radiations came from a Coolidge tube, operated at voltages ranging between 12 and 45 kv with a hexagonal copper target to various faces of which plaques of the metals Cr, Rh, Ag were attached; by an exterior magnet the target could be so rotated as to bring the different metals successively under the electron stream. The spectrometer consisted of a calcite crystal and a methyl-iodide ionization chamber. Corrections were made for absorption of X-rays before reaching the chamber, for incompleteness of absorption in the chamber, and for variations in the reflecting power of the crystal, data for the last-named corrections being taken from the work of Davis and Stempel upon the crystal used in the experiment. As finally corrected, the intensity of the $K\alpha$-line rises rapidly but not linearly with the square of the voltage; the intensity of the $K\beta$-line rises linearly with the square of the voltage; for the different metals at any one voltage, the intensity of either radiation increases in the order Ag, Rh, Cr, Cu, which is not that of the atomic numbers because Cr falls out of line; the ratio of $K\alpha$ to the general radiation of the same frequency increases with increasing atomic number (Cr does not fall out of line, in this case) and increasing voltage. The ratio of $K\alpha$ to $K\beta$ decreases steadily with increasing atomic number. The curves representing the intensity of $K\alpha$ as a function of voltage agree well with Davis' theory, the agreement being best for the two lighter elements.—[E. C. Unnewehr, Columbia; Phys. Rev. (2), *22*, pp. 528-538; 1923].

K. K. DARROW

A LABORATORY EXPERIMENT FOR TESTING THE EFFICIENCY OF A SCREW JACK

By A. P. Carman and R. F. Paton

Our object in devising this experiment has been to get a feasible quantitative college experiment which would fix the principle of work and the concept of efficiency of a machine. We chose as the machine a small screw jack, the particular jack being an inexpensive one used to lift light weight automobiles. The apparatus is shown in Figs. 1 and 2. The hand lever was removed from the gear wheel

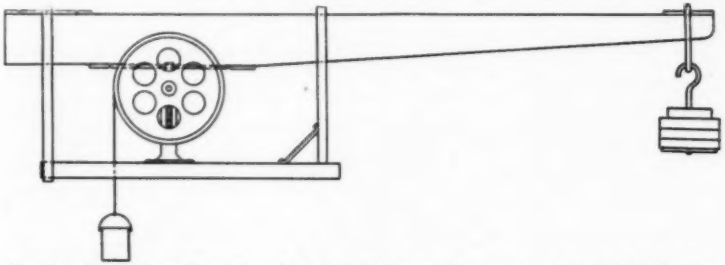

Fig. 1. *Elevation showing lever with "weight" force and screw jack with attached disk for "power" force.*

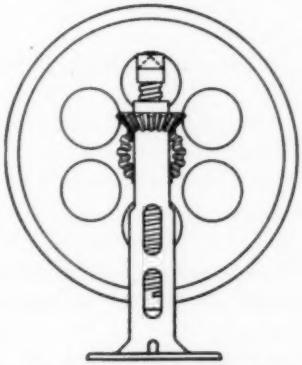

Fig. 2. Enlarged veiw of part of Fig. 1.

of the jack and a disk was substituted. The "power" force is applied as a weight hung by a wire cord which is wound in a groove on the periphery of the disk. This applies a moment of force to the small gear wheel which acts in turn on the gear turning the screw on the

jack. The "weight" force which is overcome consists of a number of large iron weights hung on the end of a lever. The fulcrum of this lever is at the opposite end of the bar and the "power" force on the lever is the force exerted by the jack. The lever as constructed by us consists of an oak beam 1.5 inches thick, about 4 inches wide and about 70 inches long. The upper end of the jack screw was fitted with a wedge-shaped piece and this rests on an iron plate screwed on the lower part of the oak beam. The point of application of this "power" force can thus be shifted along the lever bar; this point of application will not in general be under the center of gravity of the lever bar so that the work done in raising the center of gravity must be taken into account in the final calculations of the efficiency of the machine.

The following is a sample set of readings made with this apparatus.

Weight of lever	6490	grams
Pitch of screw	.847	cm
Distance of fulcrum to jack	46.0	cm
Distance of fulcrum to center of gravity of lever	66.0	cm
Distance of fulcrum to weight	166.0	cm
Distance "weight" is shifted for two revolutions of disk	6.35	cm
Distance "power" force moves for two revolutions of disk	177.8	cm
Weights at end of lever	12410.0	gm
"Power" weights in bucket required to just lift above "weight"	2040.0	gm

From the above data, the student calculates directly the following:

Ideal mechanical advantage of jack	105.
Actual mechanical advantage of jack	26.8
Ideal mechanical advantage of lever	.266
Actual mechanical advantage of lever	.230
Ideal mechanical advantage of combined machine	28.0
Actual mechanical advantage of combined machine	6.08
Efficiency of jack	25%
Efficiency of lever	86%
Efficiency of combined machine	22%.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS,
APRIL, 1924.

GRATINGS FOR SHOWING FRAUNHOFER DIFFRACTION PHENOMENA

By James Barnes

Many of the diffraction and interference phenomena discussed in text-books can be easily shown to students by means of small pieces of the screens ruled by Max Levy & Co. for halftone reproduction work.

I have selected for illustration the Fraunhofer diffraction pattern produced by parallel monochromatic rays falling normally on a screen of narrow slits and the transmitted diffracted rays brought to a focus by a converging lens. The pattern formed in the focal plane is observed with an eyepiece or may be photographed. The number of slits exposed can by varied by placing a good spectrometer slit in contact with the screen and changing the size of the opening. The width and the separation of the slits can be varied by using different screens and the wave-length changed by placing different kinds of filters in the path of the incident light.

The distribution of intensity in the pattern is given by the well-known equation:

$$I = I_0 \frac{\sin^2 \frac{\pi a \sin\theta}{\lambda}}{\left(\frac{\pi a \sin\theta}{\lambda}\right)^2} \cdot \frac{\sin^2 n\pi \frac{(a+b)\sin\theta}{\lambda}}{\sin^2 \frac{\pi (a+b)\sin\theta}{\lambda}}$$

where I is the intensity at any point of the pattern, I_0, a constant depending on the intensity of the source of light and the width of the slit, a, the width of the slits, θ, the angle of diffraction, λ, the wave-length of the light, n, the number of slits and b, the width of the opaque portion of the screen between the slits. The slits referred to in this and the following paragraphs are those of the screen and not the spectrometer slit.

For one slit ($n = 1$) the equation reduces to the first two factors,

viz, $$I = I_0 \frac{\sin^2 \frac{\pi a \sin\theta}{\lambda}}{\left(\frac{\pi a \sin\theta}{\lambda}\right)^2},$$ hence

I becomes zero when $\sin\theta = p\frac{\lambda}{a}$ where $p = 1, 2$, etc. Between these positions of darkness the intensity rises to maxima of decreasing magnitudes as p increases. Franklin[1] gives a very interesting photograph of this case in which he used a tapering slit.

For more than one slit ($n = 2, 3$, etc.) the third factor in the equation becomes zero when $\sin\theta = \frac{q\lambda}{n(a+b)}$ where $q = 1, 2$, etc.,

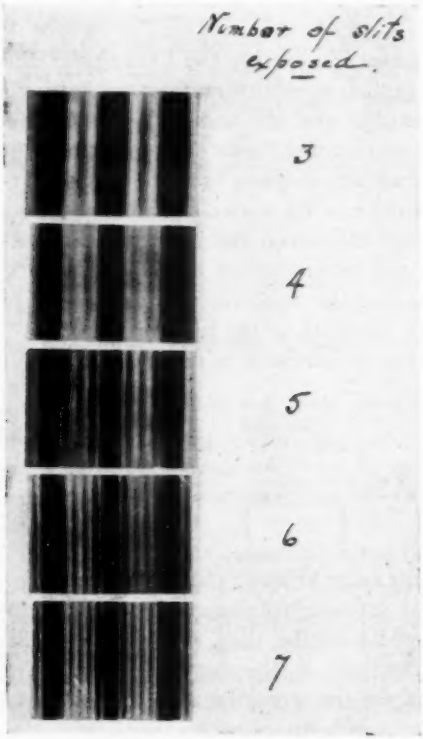

FIG. 1. *Diffraction patterns produced by 3 to 7 slits.*

with maximum values (called secondary maxima) approximately midway between the minima except in cases where q is divisible by n. Calling $\frac{q}{n} \equiv s$ then $\sin\theta = \frac{s\lambda}{(a+b)}$ where $s = 1, 2$, etc. This case

[1] Phys. Review, *14*, p. 61; 1902.

gives the positions of the maxima of greatest intensity (called principal maxima). Some of these maxima both principal and secondary may be missing if the sizes of a and b are so selected that the position of a zero value of the second factor coincides with a maximum value of the third factor.

The above equation also shows that as the number of slits is increased more and more light is thrown into the principal maxima which then become narrower with a steeper intensity gradient and thereby giving greater resolving power. The number of secondary maxima between the principal maxima is always two less than the number of slits exposed.

The figures shown on Fig. 1 are magnified *negatives* of the diffraction patterns produced by a screen with $a = 0.028$ mm and $b = 0.036$ mm. The source of light was a mercury vacuum arc with a Wratten blue filter. This filter did not transmit as monochromatic a radiation as one might desire but their filter for the green line of mercury is excellent for observational purposes. The number of screen slits exposed is indicated beside each figure.

All the physical properties of the Fraunhofer diffraction equation discussed above are shown in these photographs. Using other screens with different a's and b's the variation in dispersion and missing orders can easily be observed.

In conclusion I wish to express my thanks to Mr. Lionel Levy for giving me a number of excellent screens of different characteristics. He tells me that he will be very glad to supply others who are interested in this subject with similar screens.

BRYN MAWR COLLEGE,
BRYN MAWR, PA.

Minimum Maintaining Potential for Vacuum Arcs.—This quantity is measured upon the elements C, Na, Al and Si; the arc is apparently struck by touching the electrodes together when a potential difference V exists between them, and locating as well as possible the least value of V for which the arc will persist when the electrodes are drawn slightly apart. This minimum maintaining potential in a vacuum (degree of vacuum not stated) is located between 30 and 40 for C and for Na, between 80 and 100 for Al, between 95 and 105 for Si. The voltage corresponding to the $L\alpha$ line of the substances lies in each case within or near this range. With copper no permanent arc could be obtained with the 220 volts available. These minimum potentials are obviously much inferior to the ones in air. Note that the maintained carbon arc at 40 volts

gave as rich a spectrum as at 220, including the line near 385 A which Millikan calls the $L\alpha$-line of carbon; while the momentary flash at 30 volts does not include this line, but does include some recognized "spark" lines of carbon. [F. Simeon, Hilger Laboratory; Phil. Mag. *46*, pp. 816-819; 1923.] K. K. DARROW

The Wedge Method and Its Application to Astronomical Spectrophotometry. J. S. Plackett, Publications of the Dominion Astrophysical Observatory, *2*, No. 12; 1923.

In the first part of the paper a detailed description is given of the theory and method of use of the neutral wedge as employed by the author in the photographic determination of relative spectral energy distributions. The accuracy of the method was carefully studied by means of a gas-filled tungsten lamp at various temperatures, supplied by the Nela Research Laboratories, and an Eastman Kodak acetylene flame. Very satisfactory interchecks were obtained with these sources as standard and the color temperature of the positive crater of a cored carbon arc at 5.6 amperes, as modified by two ground glass screens, was found to be $3080° \pm 30°$ K.

The spectral energy distribution giving this color temperature was taken as standard in the measurements made upon the sun and some stars, as described in the second part of the paper. Measurements on the sun were made on July 21, 1921, as day of exceptional transparency, and were corrected to give the energy distribution outside the earth's atmosphere. Great care was exercised to make measurements on small regions of the spectrum containing only the faintest of the Fraunhofer lines. It is to this precaution that the author attributes the difference between his results and those of Abbot and Wilsing, the author obtaining distinctly higher relative values below 0.47 μ than do the other two investigators. The agreement throughout the rest of the spectrum is good. The author's data would give a color temperature of 6700° to 7000° K.

Spectral energy data are given for several of the stars, but because of certain unsolved difficulties in the observational method as thus applied, the author considers the results as still somewhat tentative. Comparisons are made with data by other investigators.

The author discusses rather fully the various errors possible in the method, giving his precision throughout the paper, and would seem to have covered all such possibilities unless in the use of the ground glass screens. He assumes these diffusing surfaces to scatter unselectively. This is often not the case and the resulting possible selective transmission may account for the low value of 3080° for the 5.6-ampere carbon arc, as compared with Priest's value of 3420° for the 10-ampere arc. If there be this selective transmission in the screens that the author uses it will affect the values obtained by him for the sun's spectral energy distribution, since they were used to reduce the intensity of the sun's spectrum in those measurements. K. S. GIBSON

A COMPACT DISTILLATION APPARATUS

By Frederick Kraissl

The accompanying diagram shows a convenient form of water still to be used for furnishing small quantities of distilled water where a larger supply is not readily available. The operation of the apparatus is obvious, water from the Erlenmyer flask being condensed in the pyrex condenser by aid of a circulating stream of cold water, the rate of production being 300 to 400 cc per hour.

For most purposes it is sufficient to connect the condenser to the flask by means of a rubber stopper. But where greater purity of product is required, as for example in intravenous injections, connection can be made by ground joint.

Corning Glass Works,
Corning, N. Y.

State of Atoms Emitting Line Spectra.—A beam of anode rays consisting of charged and uncharged atoms of Li, Na, or K, shoots through a small slit in the cathode of the discharge tube into a highly evacuated chamber. The faintly luminous pencil extending from the slit into the vacuous chamber is ascribed to atoms which were excited before or during passage through the slit. A transverse electrostatic field is applied to it, and it is photographed with a spectrograph. Lines of the principal and subordinate series are observed, and all are straight, whence Rupp concludes that these series are emitted from atoms which are neutral during emission. The same observation is made upon lines of the Balmer series, produced when the discharge tube contains hydrogen. Spark lines of oxygen appear when there is oxygen in the tube, and the images are curved, from which it is deduced that the spark lines are emitted from atoms which are positively charged during emission. These results are compatible with contemporary atom models. Less explicable are certain results obtained when the second chamber is less completely evacuated. The luminous pencil becomes broader and brighter, because of excitations occurring within the second chamber itself. Under these circumstances it would be curved if the particles were charged up to the moment of excitation. When examined with a spectrograph, the images of lines of the principal series are found to be straight; those of spark lines are curves, indicating that the atoms are neutral up to the moment of excitation in the first instance, positively charged in the second. This too is comprehensible; but it is strange that the images of lines of the subordinate series are also curved, as if an atom could not emit these without previously being positively charged. A comparison is made with the distribution of emission lines in arcs, and a generalization as to the behavior of various series in the spectra of alkaline-earth metals, which has equally curious features. [E. Rupp, Heidelberg; Ann. d. Phys. *74*, pp. 1-15; 1924.]

K. K. DARROW

THE TECHNICAL LABORATORY OF THE APPARATUS HOUSE

Its Functions and Organization

By Paul E. Klopsteg*

The company with which the writer is connected is both manufacturer of and dealer in laboratory apparatus and chemicals. Its merchandise includes several thousands of items of different kinds, and this fact alone indicates the complicated nature of the business. The manufactured product comprises all apparatus used in the teaching of high school and college chemistry and physics, together with many of the laboratory supplies which are used in the processes employed in the various kinds of industrial laboratories. The remaining part of the line consists of materials purchased elsewhere, consisting principally of such things as glassware, porcelain and rubber goods, and certain special kinds of instruments which, because of uses in other fields, are produced in large quantity, and which, for this reason, can be purchased at a lower price than the cost of manufacture in limited quantities. It is obvious that the kind of service which such a company may reasonably be expected by its customers to give requires close supervision over the production and purchase of every one of its items, from the one cent test tube to the thousand dollar spectrophotometer. The requirements of a business of this nature, which is probably typical of the apparatus houses in this country, will be the basis upon which the subject indicated in the title will be discussed.

The Technical Laboratory deals almost entirely with questions and problems incident to the apparatus business; it is concerned with apparatus for physics, chemistry, biology, and other experimental sciences. Here especially the fact must be kept in mind that every instrument and every laboratory appliance, regardless of the science for which it is intended, is essentially a physical measuring instrument, or an appliance in the use of which physical processes are involved. This is necessarily so because any instrument in any laboratory involves observation of some sort by the experimenter, and observation is nothing more than the observer's paying attention to and making note of physical reactions of the apparatus or instrument upon his own perception. A safe guide in the study of apparatus or in the develop-

* Director in charge of Development and Manufacturing, Central Scientific Company.

ment of some new instrument is the plan of always giving proper attention to the physical fundamentals involved. This important question has been discussed at length by the writer.[1]

QUALIFICATIONS OF THE LABORATORY STAFF

The research physicist or chemist in the Technical Laboratory must, for reasons given, be well grounded in physics, but at the same time he must have at least a speaking acquaintance with the sciences for which the apparatus is designed. Further than that, he must have what might be called a sixth sense, namely, the "apparatus sense." He must have an instinct or a "feel" for apparatus, and after some experience in the work he must be able to deduce quickly, merely from an examination of the piece in question, what are its purposes. At the same time there must immediately come up in his mind the question, "Could this piece be improved so as to perform its functions better or more quickly or with greater convenience to the observer?" and several answers will at once suggest themselves to him. There is another requirement. He must have enough knowledge of manufacturing processes so that among different designs he can intelligently choose those features which lend themselves to economical manufacture, and combine them in what approximates the ideal, both from the manufacturing and the technical points of view.

ORGANIZATION OF THE TECHNICAL LABORATORY

There is probably no single apparatus manufacturer in the country for whom it would not be a good plan to assign to his Technical Laboratory a number of functions. Taking these in logical sequence the functions may be classified somewhat as follows:

(a) Development of new apparatus or instruments, and research on theoretical problems incident to such development.

(b) Technical inspection of the manufactured product.

(c) Technical inspection of manufacturer's samples submitted for catalog listing, and of purchased merchandise.

(d) Investigation of the technical aspects of complaints and criticisms from customers.

These functions will be briefly discussed.

DEVELOPMENT AND RESEARCH FUNCTIONS

The Development Section of the Technical Laboratory is primarily concerned with the scientific development into practical form of an idea

[1] Science, *50*, p. 199; 1919 and *51*, p. 384; 1920.

for an instrument or of a laboratory appliance, which may have been suggested either by someone outside the organization whose work may have indicated a need for such a piece, or it may have been a by-product of some earlier development work. A typical development may, for example, consist first, of a thorough-going study of all available references to the subject, combined with research on its theoretical aspect. On the basis of this work an experimental design is evolved. A model is then built and thoroughly tested. Usually the tests at once reveal or suggest points which are capable of improvement. A study of the first model may and usually should result in simplification and improvement of design.

Often the scientific study involved in the development process makes necessary the design and construction of special apparatus. As an illustration of this point may be mentioned the very extensive development problem of working out the correct design of such electrically heated and automatically controlled constant temperature devices as water baths, incubators, and drying ovens. In this study it is necessary to decide first what precision of temperature control at any given point in the bath or air chamber is required, and what uniformity of temperature throughout the bath or chamber is necessary. To determine whether in a given design the requirements are met both during short intervals and over very long periods of operation, two alternative methods are possible. The one is to have the experimenter make periodic observations at short intervals for hours or days at a time, using instruments for making the measurements which have the required degree of accuracy. This procedure is extremely time-consuming, and there is no question but that the observer's time could be spent to better advantage. The other procedure is to construct an automatic recording device, the sensitiveness of which can be adjusted to suit the requirements of the most precise control, as well as those less exacting in their demands for precision. In the course of an investigation, such a recorder has been designed and built. Two simultaneous photographic records are obtainable by the deflection of sensitive galvanometers opening on thermoelements. A sensitiveness of .001°C for 5 mm on the record can be obtained. The photographic record automatically has one minute intervals recorded on it, and it comes out of the recorder developed, fixed, washed, and dried. The great saving of time and of nerve-exhausting work, and the fact that permanent records are

secured by means of the device, are sufficient justification for the considerable expense involved in its design and construction.

THE DESIGN COMMITTEE

After the Development Section has completed its work on a particular apparatus, a conference of a "design committee" takes up the question of mechanical design of an apparatus which will embody all the essential features of the model, and which, at the same time, will be simple and economical to manufacture. A number of alternative designs are usually worked out by one of the designing engineers and submitted to the committee, and again the best features of each of them combined into one which approaches the best possible form. Usually a final model is then constructed in which the remaining defects, if any, will be minor ones; these can easily be corrected in the working design upon which quantity production is based.

The design committee will, in general, include the development engineer, the chief designer, the production manager, and the chief inspector, together with a representative of the sales department, under the chairmanship of the manager of the division which includes these various activities, all of whom must have intimate knowledge of the apparatus, but who regard it from entirely individual and distinct points of view. It is hardly necessary to point out how advantageous it is if several or all of these individuals have, at one time or another, been purchasers and users of scientific apparatus. A conference of this kind saves much time, because by the elimination process, most rigorously and unsparingly applied, there is likely to be left a combination of features which will have merit because they have survived the criticism from so many different points of view. A design so evolved is therefore much more likely to find immediate favor with the buyer and escape his criticism than one which has been worked out from start to finish by an individual whose points of view may all have been condensed into a rather narrow angle of vision because he has lived with the job so closely. In the individual the problem usually becomes so much a part of him that he is unable to apply the sort of criticism that must be applied to a design before it can be successful.

THE INSPECTION FUNCTION

The Inspection Branch of the Technical Laboratory is one of the most important, because any inefficiency or carelessness at this point must

inevitably result in dissatisfaction on the part of users of the apparatus. The inspection of the manufactured as distinguished from the purchased article must in general be of two kinds. First, there must be mechanical inspection to determine whether the manufacturing specifications have been followed and whether material, finish, and general workmanship are satisfactory. In addition most pieces require technical inspection also, to determine correctness of performance. Improvement of design in apparatus can be very largely aided by an efficient inspection department, because it is here that the critical attitude of mind must be maintained, and it is this attitude which most successfully brings out imperfections of design or construction. Such criticisms can be reported to the design committee, and usually a suggestion as to possible improvement can be adopted without difficulty.

One other important duty of the chief inspector—a duty incident to his supervision of the inspection activities—is a study of manufacturing specifications and their coordination with specifications for inspection of the corresponding item. In an extensive line this in itself is a large task. Each item requires careful consideration of such questions as tolerances in dimensions and precision or accuracy in performance. For example, careful discrimination must be exercised in establishing tolerances in different kinds of glass apparatus and in apparatus made of wood and metal. In apparatus constructed of glass there may be one or two dimensions which must be maintained rigidly, whereas other dimensions may vary within wide limits without affecting the utility of the piece. The inspector must be able to decide not only which dimensions are important from the point of view of performance, but how much latitude of variation is allowable in the various dimensions. In glass apparatus one easily falls into the error of requiring unnecessary accuracy in all dimensions. This brings with it needless expense on account of the much greater time which the glassblower has to put on the job in order to meet such requirements. In apparatus made of wood it is also possible to err on the side of tolerances that are too exacting. The inspector must keep in mind the fact that wood, no matter how well seasoned and dried, may experience changes in dimensions on account of warpage, expansion or shrinkage due to atmospheric or other conditions. He must set his limits wide enough to make the necessary allowance for these variations, but not too wide to affect the proper functioning of the instrument. Sometimes a study of this question in connection with apparatus partly made of wood results in a recommendation to change the design and replace the wood by metal

or some other substance which will maintain its dimensions within the required limits.

It is obvious that to cover every item in a line comprising thousands as thoroughly as has just been indicated is an almost impossible task without encumbering the overhead expense incident to manufacture in a measure which is out of proportion to the value of the product. This puts an additional responsibility on the chief inspector. In instances where definite limits have not been established, it becomes a matter for his judgment to say whether an article shall or shall not pass inspection, and intelligent judgment on such questions can be formed only on the basis of experience in the use of such apparatus, and a consequent intimate knowledge of its functions.

Another aspect of the inspection function is the inspection of samples of apparatus from other manufacturers to determine whether or not they measure up to the standards of the apparatus house. In this function the Technical Laboratory renders service to the sales department by giving the latter authoritative information, on which rests its decision to list or not to list the item submitted. Wherever possible it is advantageous to purchase merchandise from reputable manufacturers who themselves maintain strict standards, and whose products therefore require little attention when they are received for stock. Occasionally, however, a piece of apparatus, having merit in its conception, is manufactured by an individual or a small organization where the standards, if there are any, may vary, or where standards are sometimes forgotten in order to "get out the stuff." The apparatus house in listing an item of this sort necessarily takes upon itself the responsibility of guaranteeing to its customers the satisfactory performance of the item in question just as it would in the case of its own product. In order to do this effectively there must be a thorough inspect on of the article when it is received. Any defects which are so discovered are then immediately reported to the manufacturer and replacement or other adjustment made. Such inspection is especially important in the case of special glassware which is purchased from glassblowing shops not connected with the organization. In this instance inspection includes examination for grade of material, conformity with blueprints and specifications, and of workmanship in general.

TECHNICAL SERVICE TO CUSTOMERS

Many of the complaints which are received by an apparatus house are with reference to performance of an instrument or of a laboratory

appliance. When such complaints are received someone in the Technical Laboratory may be assigned to analyze the difficulty and suggest a remedy if possible. This becomes easier if the apparatus in question is returned for examination. In many instances the apparatus has been used in a manner which had not been contemplated, or for a purpose for which it had not been intended. In some cases there may have been a defect which could not be discovered at the time of inspection. Whenever the cause of the difficulty cannot be determined for lack of sufficient data, and even in many cases in which the customer has clearly been at fault, the laboratory may recommend an adjustment on the basis that the customer was right for the reason that the complaint may have suggested a possible way of improving the item in question. The customer-always-right policy for an apparatus house is undoubtedly a good-will builder, although it may be difficult at times to carry out, especially when investigation by the Technical Laboratory has demonstrated that the customer was wrong.

Practically all apparatus is accompanied by some sort of instructions or direction sheets, and the Technical Laboratory has the responsibility of writing directions and supplying them with the apparatus. Clear, explicit directions save correspondence and ward off complaints. The function of supplying adequate directions places the responsibility for proper instruction to the user upon those who are most familiar with the purpose of the apparatus. In this manner greatest likelihood of satisfactory results is secured.

Technical information is often supplied by the Laboratory to customers or prospective customers in a more direct way than merely investigating complaints or giving advice tantamount to the writing of instructions. This consists in the answering of inquiries made by customers, for example, about the suitability of certain apparatus for their purposes, or about the best method and technique for meeting some phase of their research problems. Often literature references are given, many of which are on file as the result of earlier study of the questions at issue.

EQUIPMENT OF THE TECHNICAL LABORATORY

In order to perform the functions which have been outlined above it is necessary that the Laboratory be equipped with all the facilities needed to perform these functions easily, accurately, and without loss of time. On account of the variety of articles which pass thru the Inspection Branch of the Laboratory, it is necessary to have apparatus

for various kinds of mechanical, electrical, acoustic, optical, and thermal tests, and to maintain numerous standard instruments and gages. Frequent checking and calibration of the standards is one of the most important duties of the inspection department, and a related activity, which is by no means a minor one, is the development of new methods of and apparatus for inspection tests.

The equipment of the Development Section of the Technical Laboratory must consist in the first place of the common aids to development work, consisting of ring stands and other kinds of supports, clamps, heaters, vacuum pumps, meters of various kinds, etc. There must be the recognition, however, that any particular development job may require special apparatus, an example of which has already been cited.

By no means the least important item of equipment is the technical library, which should contain the most important technical reference volumes in the various sciences with which the Laboratory has to deal. It should include also a complete assortment of the various high school and college texts and manuals in the common experimental sciences. Finally, there should be current files and bound volumes of the various scientific and engineering journals, so that there may be easy access to knowledge of progress in these fields. It would be needless expense to attempt to maintain a large library, containing books to which reference might never be made. Unusual problems are best handled by making use of the excellent technical library facilities which are to be found in most large cities or universities.

CONCLUSIONS

Science has never made more rapid progress than at the present time, and much of the progress in science would be impossible without apparatus with which data may be obtained and deductions verified. It follows that any apparatus house which does not maintain a Technical Laboratory is hardly in position to keep abreast of the requirements of those whose needs make its business possible. When one considers the complexity of the business and the tremendous possibilities for trouble, together with the obligations of the apparatus house to its customers, it is difficult to see how any apparatus house can hope to continue in the confidence and good will of its customers unless it maintains an efficient Technical Laboratory, built up along the general lines which have been described.

CENTRAL SCIENTIFIC CO.,
CHICAGO, ILLINOIS

FINAL REPORT OF RETIRING SECRETARY

THE OPTICAL SOCIETY OF AMERICA

(April 26, 1924)

This report covers business from October 28, 1923 to April 26, 1924, inclusive. It follows the report dated November 22, 1923, published in J.O.S.A. & R.S.I. *8*, pp. 38-43; January, 1924.

I. CHANGES IN THE MEMBERSHIP

The membership as last of record preceding the present report was given in synposis on p. 39, J.O.S.A. & R.S.I., January, 1924. The Directory of Members as of October 27, 1923 was published, pp. 55-75, J.O.S.A. & R.S.I., January, 1924. A revised and corrected edition of this Directory was published as a separate reprint under date of March, 1924.

The following changes and corrections will bring these publications up to date insofar as the Secretary has information.

1. Elections.—The following have been elected to Associate Membership in accord with Art. 1, Sec. 3, of the By-Laws. These names should be reviewed by the Council at the next Annual Meeting in order that appropriate action may be taken in the matter of transfer to Regular Membership:

399 W. F. HAMILTON, 101 Chestnut St., Louisville, Ky.
400 Karl K. DARROW, 610 West 111th St., New York, N. Y.
401 Samuel Edward SHEPPARD, 83 Gorsline St., Rochester, N. Y.
402 Turner C. BROWN, c/o Bausch and Lomb Opt. Co., Rochester, N. Y.
403 Jonas B. NATHANSON, Carnegie Institute of Technology, Pittsburgh, Pa.
404 John R. FREEMAN, 815 Grosvenor Bldg., Providence, R. I.
405 Forest K. HARRIS, U. S. Bureau of Standards, Washington, D. C.
406 Fred H. PERRIN, 62 Sagamore Ave., West Medford, Mass.
407 John Bertrand JOHNSON, 463 West Street, New York, N. Y.
408 Walter H. STAINTON, Rockefeller Hall, Cornell University, Ithaca, New York.
409 John C. SHEDD, Department of Physics, Occidental College, Los Angeles, California.
410 Gano DUNN, 20 Washington Square, New York, N. Y.
411 Bergen DAVIS, Department of Physics, Columbia University, New York, N. Y.
412 Samuel E. POND, 1863 Colonnade Road, Cleveland, Ohio.
413 Charles E. ST. JOHN, Mt. Wilson Observatory, Pasadena, California.
414 Elmer A. HARRINGTON, 7 Allen St., Amherst, Mass.
415 Arthur POPE, Department of Fine Arts, Harvard University, Cambridge, Mass.
416 Harold W. WEBB, Assistant Professor of Physics, Columbia University, New York, N. Y.
417 Deane B. JUDD, 281 13th Avenue, Columbus, Ohio.
418 Newell C. PAGE, Massachusetts Institute of Technology, Cambridge, Mass.

2. Resignations.—The resignations of the following members are on file to be laid before the Council at its next meeting:

L. F. YNTEMA, M. D. Ewell,
J. M. MCCALLIE, H. O. STEARNS,
Lucien HOWE, Gordon F. HULL (to be effective December 31, 1924),
C. McCheyne Gordon, H. C. LORD,
E. P. HYDE, Charles F. PRENTICE.

3. Changes of Address.—Notices of change of address have been received as follows:

New Address	*Old Address*
C. D. MILLER, R. D. 1 Millis, Mass. (Effective May 1)	University of Manitoba, Winnipeg, Canada.
Samuel E. POND, Washington University School of Medicine, Euclid Avenue and Kingshighway, St. Louis, Mo.	1863 Colonnade Road, Cleveland, Ohio.
E. P. T. TYNDALL, Department of Physics, University of Iowa, Iowa City, Iowa.	Western Electric Company, 463 West Street, New York, N. Y.
Fred E. ALTMAN, Hawk-Eye Works, Eastman Kodak Company, Rochester, N. Y.	27 Lake View Terrace, Rochester, N. Y.
Carl F. DIECKMANN, 4534 Virginia Ave., Chicago, Ill.	N. E. Cor., Fullerton and Sheffield Ave., Chicago, Ill.
Gordon H. GLIDDON, 13 West Wheelock St., Hanover, N. H.	11 Fairview Heights, Rochester, N. Y.
George W. SHERMAN, Jr. 8 Murdock Apts., West Lafayette, Indiana.	No. 4 Murdock Flats, West Lafayette, Indiana.
Conrad A. STONE, P. O. Box 391 Charleroi, Pa.	521 Washington Avenue, Charleroi, Pa.
W. F. G. SWANN, Ryerson Physical Laboratory, University of Chicago, Chicago, Ill.	Department of Physics, University of Minnesota, Minneapolis, Minn.

4. Life Membership.—Gano DUNN has applied for Life Membership.

5. Death.—Ralph C. Rodgers died January 11, 1924.

No other notices of death have reached the Secretary.

6. Unknown Address.—The correct address of Ralph S. Dobbins is unknown to the Secretary. Registered mail addressed to him is returned unclaimed.

II. REFERENCE LIST OF OFFICIAL NOTICES PUBLISHED BY THE SECRETARY

(Continuation of List, J.O.S.A. & R.S.I., *8*, p. 43; 1924)

Proceedings, Eighth Annual Meeting.—(Including Minutes of Executive Council, Secretary's Report, Etc.), J.O.S.A. & R.S.I., *8*, pp. 21-45; January, 1924.

Proceedings, Eighth Annual Meeting, (abridged).—Science, pp. 451-452; November 30, 1923.

Constitution, By-Laws and Membership.—J.O.S.A. & R.S.I., *8*, pp. 47-75; January, 1924. (Revised Edition, Separate Pub., March, 1924.)

Notice of Appointment of Committees.—J.O.S.A. & R.S.I., May, 1924.

Notice of Change of Secretary.—J.O.S.A. & R.S.I, May, 1924.

III RECORDS OF THE SOCIETY

The Constitution and By-Laws as amended to date were last published, pp. 49-51, J.O.S.A. & R.S.I., January, 1924. There have been no amendments since this publication.

Besides general correspondence files, I am transferring the essential records of the Society to my successor in the following form:

Three bound volumes as follows:

(1) Early Records of the Society
(2) Records of Election to Membership to close of Eighth Annual Meeting
(3) Reports and other Official Notices of the Secretary, 1921–1924.

Four loose leaf binders as follows:

(1) Constitution, By-Laws and Minutes of the Executive Council
(2) Current Records of Election to Membership
(3) Business Awaiting Action of the Executive Council
(4) Programs and Proceedings of the Annual Meetings.

IRWIN G. PRIEST,
Retiring Secretary.

A Theory of the Variation of the Intensity of a Spectrum Line with the Density of the Emitting Gas.—Beatty and others have observed that the intensity of a spectrum line, for example $H\alpha$ emitted from a Geissler tube, increases to a maximum and then decreases as the pressure of the gas is increased. The initial increase is ascribed to the increase in the number of particles capable of emitting; the subsequent decrease, to interference between particles when they are close together. Strum tries to refine this interpretation by conceiving a random arrangement of NA atoms over an area A. For an atom selected at random, the probability that there will be no other atom within a distance r(center to center) is $\exp(-N\pi r^2)$, by a formula of Smoluchowski's. It is assumed that emission of a given spectrum line can occur only from an atom, the minimum distance of which from another atom exceeds a fixed amount such as (e.g.) the radius of the initial orbit of the valence electron. The number of quanta of a given frequency emitted per second from the above atom-arrangement would then be as $N \exp(-N\pi r^2)$, where r is a constant of the spectrum line, increasing with the azimuthal quantum number of the initial orbit. Putting N in the exponent proportional to $p^{2/3}$, and N in the factor proportional to p, Strum obtains a function of p having the required maximum and agreeing very well in shape with Beatty's experimental curve for $H\alpha$, although no attempt is made to obtain an agreement in absolute values.—[L. Strum, Kieff; ZS. f. Phys. *18*, pp. 372-378; 1923].

K. K. DARROW

Dependence of the Intensity of X-ray Emission Lines on the Energy of the Bombarding Electrons.—Experimental work on the intensity of the $K\alpha$ and $K\beta$ lines of chromium; the $K\alpha$, $K\beta$, and $K\gamma$ lines of copper; the $K\alpha$ line of silver; the $L\alpha$ and $L\beta$ lines of lanthanum, and the $L\alpha$ line of lead. The range of voltages extend up to about 50 kv. The intensities of the lines were measured photographically, the duration of the exposure being modified when the voltage was changed, in such a way that the blackness of the line was about the same in all cases. The in-

tensity versus voltage curves are at first concave upward. At higher voltages some of them pass through points of inflection and become concave downward; it is supposed that as the speed of the electrons is increased the additional x-rays which they generate come on the average from deeper layers of the metal and are more considerably absorbed on their way out. The arrangement of the apparatus favors this, as the electrons were incident at nearly normal incidence, while the X-rays received on the films issued at nearly glancing emergence. The author compares his results with the theoretical intensity-versus-voltage relation of Bergen Davis, which depends on a parameter $\mu c/b$; μ is the coefficient of absorption of the x-rays in the metal; b is the coefficient in the equation $V^2 - V_0^2 = bx$, where $V^2 - V_0^2$ is the loss in energy of an electron in passing through a distance x within the metal; c is the cotangent of the angle of emergence of the x-rays. Knowing μ by direct measurement, and estimating b from observations on metals different from those used in these experiments, the author adjusts $\mu c/b$ to produce the best possible agreement between theory and experiment; the value of c required to do this is quite plausible; hence the theory is considered to be substantiated.—[G. Kettmann, Berlin; ZS. f. Phys. *18*, pp. 359-371; 1923].

K. K. DARROW

Spectral Series in the X-ray Spectrum of Iron.—Rollefson employs the conventional method of bombarding an iron disc with thermionic electrons of voltage V, measuring the photoelectric current i from a platinum disc exposed to radiation from the iron, plotting i versus V and looking for "breaks" in the curve. He ascribes his success in finding numerous "breaks" largely to shielding the glass walls of the tube with metal plates and gauzes which could be maintained at definite potentials, avoiding electrostatic effects from charges accumulating on the glass. In the range of voltages between 160 (λ 77A) and 264 (λ 46.8) be observes nine breaks, and calculating the equivalent frequencies he finds that seven of them agree quite well with the values of the function $(a - b/n^2)$ for $n = 5$, 6, 7, 8, 9, 10 and 12 respectively. This indicates that they belong to a series with convergence wave length at 69.4, corresponding to an extraction potential of 177 volts for a certain level. This level is identified, with the assistance of the two other breaks and of three breaks between 600 and 700 volts, as the M_5 level. The two other breaks in the range 160-264 are due to electron transitions ending at the M_3 level with an extraction potential of 152 volts; one of them is a transition beginning at the L_1 level which thus has an extraction potential of 800 volts. The three breaks in the range 600-700 volts are due to the transitions M_5L_1, M_5L_2, M_1L_1. The numerical agreements with frequencies in the K series, obtained by using the combination principle on these data, are good; and the evidence for the quoted attributions of the various lines, as well as for the existence of virtual orbits into which the M_5 electrons can be lifted, seems strong.—[G. K. Rollefson (California) Phys. Rev. *23*, pp. 35-45; 1924.]

K. K. DARROW